Lawrence Livermore National Laboratory

March 2013

Science & Technology Review

TECHNOLOGY SOLUTIONS FOR LOW-COLLATERAL-DAMAGE MUNITIONS

Also in this issue:

Pursuing the Grand Challenge of Ignition

Gene Regulation to Build Better Bones

From Turbulence to Self-Organized Plasma

About the Cover

The article beginning on p. 4 describes the Laboratory's contributions to advanced technologies for the Joint Department of Defense/Department of Energy Munitions Technology Development Program (JMP). Long-term investments in computational codes, computing and manufacturing infrastructure, and engineering expertise provide the resources needed to help speed delivery of new weapons technologies to sponsors. One such project focused on BLU-129/B, a munition that improves near-field lethality and reduces collateral damage—critical concerns for warfighting in urban environments. The cover shows (from left) Dennis Freeman, Lee Griffith (behind the device), and David Hiromoto positioning a case prior to structural testing. Other JMP-related work includes research on firing systems, computational mechanics and materials modeling, warhead applications, technologies to penetrate hard targets, and energetic materials.

Cover design: Amy E. Henke.

About *S&TR*

At Lawrence Livermore National Laboratory, we focus on science and technology research to ensure our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published eight times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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Science & Technology REVIEW

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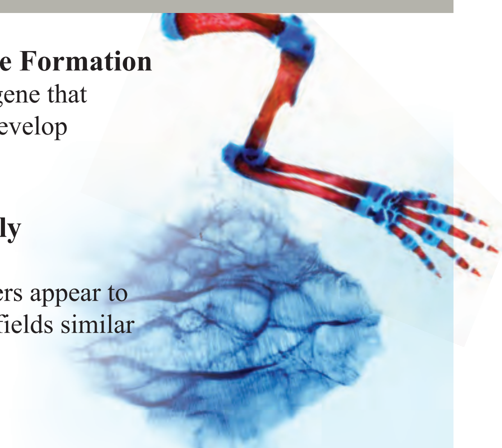

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Researchers Solve Condensed-Matter Physics Puzzle

A research collaboration led by Livermore scientist Magnus Lipp and former Laboratory scientist Joseph Bradley has answered a long-standing question in condensed-matter physics regarding the large isostructural volume collapse that cerium undergoes at high pressure. Scientists have been debating about the fascinating behavior of this rare-earth element since the 1970s. The team, which included colleagues from the University of Washington, Stanford University, SLAC National Accelerator Laboratory, and Carnegie Institute of Washington, found an experimental signature that strongly favors one of the proposed models, called the Kondo Volume Collapse. Understanding this unusual behavior is important because cerium can be used as a catalyst and a fuel additive.

As part of this study, the researchers developed a methodology that uses x-ray spectroscopy to study rare-earth systems at high pressure and directly probe quantum mechanical observables, which makes the methodology a powerful test of theory. The collaborators also built instrumentation that speeds up data collection by a factor of 100 or more. Results from the study appeared in the November 9, 2012, edition of *Physical Review Letters*.

"As a result of this work, we can not only answer the cerium question," says Bradley, "but we can also study many systems and gain some real understanding about *f*-electron delocalization in general, which is a 'holy-grail' question in condensed-matter physics and one that can be directly transferred to the 5*f* electron in actinides."

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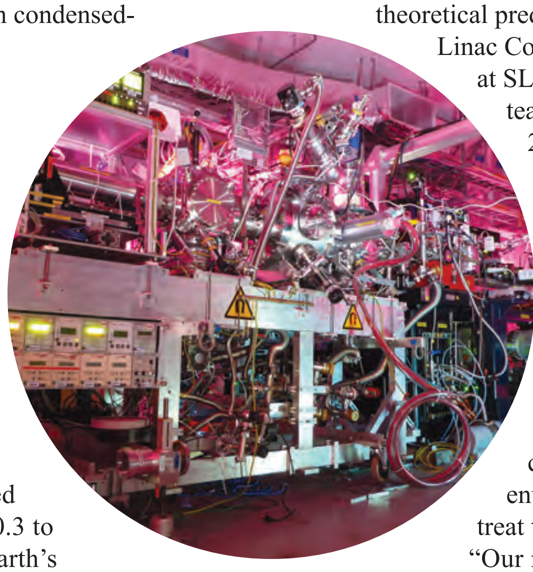
New Clues to Planetary Evolution

A new understanding of planetary evolution could emerge from experiments on magnesium oxide under high pressures and temperatures. Scientists from Lawrence Livermore and the University of California at Berkeley, working at the University of Rochester's Laboratory for Laser Energetics and at Livermore's Jupiter Laser Facility, subjected magnesium oxide to pressures from about 0.3 to 1.4 trillion pascals (3 to 14 million times Earth's atmospheric pressure) and temperatures reaching up to 50,000 kelvins—conditions found at the center of Earth and in giant "super-Earth" planets in other solar systems. The molecular bonding of the mineral samples changed substantially in response to these extreme conditions, including transformation to a new high-pressure solid phase not previously observed. In fact, the team's results indicate that when magnesium oxide melts, it changes from an electrically insulating material such as quartz to an electrically conductive metal similar to iron.



Drawing from these findings and other recent observations, the team concluded that although magnesium oxide is solid and nonconductive on present-day Earth, early Earth's magma ocean might have been able to generate a magnetic field. Likewise, the metallic, liquid phase of magnesium oxide can exist today in the deep mantles of super-Earth planets, as can the newly observed solid phase.

"Our findings blur the line between traditional definitions of mantle and core material and provide a path for understanding how young or hot planets can generate and sustain magnetic fields," says Stewart McWilliams, who led the project as part of the research for his Ph.D. thesis. Livermore scientists Jon Eggert, Peter Celliers, Damien Hicks, Ray Smith, and Rip Collins also contributed to this study, which was published in the December 7, 2012, issue of *Science*.

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X-Ray Laser Takes Aim at Cosmic Mystery

In a series of free-electron laser experiments on highly charged iron, an international collaboration involving Livermore researchers has identified a new solution to an astrophysical phenomenon, which will help scientists understand why observations from orbiting x-ray telescopes do not match theoretical predictions. This study was conducted with the Linac Coherent Light Source (LCLS, shown at left) at SLAC National Accelerator Laboratory. The team's results appeared in the December 13, 2012, edition of *Nature*.

Highly charged iron produces some of the brightest x-ray emission lines from hot astrophysical objects, such as galaxy clusters, stellar coronae, and the Sun. However, its spectrum does not fit into even the best astrophysical models. The intensity of the strongest iron line is generally weaker than predicted. Scientists have questioned whether this discrepancy is caused by incomplete modeling of the plasma environment or by shortcomings in how models treat the underlying atomic physics.

"Our measurements suggest that the poor agreement is rooted in the quality of the underlying atomic-wave functions rather than in insufficient modeling of collision processes," says Livermore physicist Peter Beiersdorfer, who helped initiate the project. This study paves the way for future astrophysics research using free-electron lasers such as LCLS, which for the first time allows scientists to measure atomic processes in extreme plasmas in a fully controlled way.

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Commentary by Monya Lane

Long-Term Investment Drives Engineering Innovation

LIVERMORE'S broad, diverse missions are both enduring and ever-changing. They demand foresight, rigor, and an unwavering commitment to making innovative scientific and technological advances. Accomplishments throughout the Laboratory's history have demonstrated how our multidisciplinary team approach to problem solving leads to improved capabilities for addressing tough national security challenges. These efforts are further enhanced through long-term investment strategies, extensive research and development programs, and the ability of Livermore's scientists and engineers to anticipate the future needs of our sponsors and our missions.

The benefits of long-term investment and forward thinking are readily apparent in the Laboratory's Joint Department of Defense/Department of Energy Munitions Technology Development Program (JMP). As discussed in the article beginning on p. 4, JMP is leading efforts to develop advanced technologies to meet the evolving needs of the nation's warfighters. Through this program, many emerging technologies for advanced weapons capabilities get their start and transition to military applications. The program incorporates high-performance computing, material processing and mechanical behavior studies, and computational and design engineering to rapidly deliver new technologies to our sponsors.

JMP was the starting block for what has become one of the Laboratory's recent crowning achievements: the design, fabrication, and manufacture of an advanced conventional munition called BLU-129/B. Together with the U.S. Air Force and an industrial partner, the Laboratory developed BLU-129/B in response to an urgent need for a low-collateral-damage weapon with improved near-field lethality. Our past research to examine the dynamic behavior of composite materials, characterize explosives, and design filament winding carbon-fiber composites made us ideally suited for the task.

The Laboratory's multiyear foundational work in fiber composites is exemplary project showing how long-term investment in a particular technology can lead to its use in various applications. Over the last several years, the Laboratory's research has increased the use of fiber composite materials in our programs and in many industrial applications. During this time, Livermore also established its advanced composite engineering facility to fabricate and manufacture fiber composite materials for broader applications. Designs for low-collateral-damage weapons such as the BLU-129/B would not have been possible without the continued investments and research efforts dedicated to fiber composites and explosives characterization. This ongoing work allows us to quickly address sponsor needs as they arise and deliver solutions to problems that demand almost immediate results. As noted in the feature article, the BLU-129/B warhead was completely fielded in record time: a mere 18 months.

Our sponsors depend on us to stay at the leading edge of technology advancement. We rely on our engineering technology leaders to have the vision for and knowledge of our mission to imagine what is possible in the future. Every year, we look at what technologies we are currently developing and what new ventures should be pursued to advance technologies for mission-related and sponsor-driven applications. The task is not an easy one, but it has yielded fruitful results over the years.

In late 2012, Laboratory Director Parney Albright outlined three key initiatives for Lawrence Livermore programs for 2013 and the immediate future: big data (supercomputing), materials development and manufacturing, and bioengineering systems. Under these initiatives, we are tasked with developing novel material compositions and integrating an advanced manufacturing strategy to produce certified parts and prototypes at Livermore. Our core competencies in computational and materials engineering have positioned the Laboratory to be a leader in accelerating the development and manufacture of advanced materials to meet the demands of our broad missions. As with the BLU-129/B project, we have successfully applied our expertise in large-scale, high-fidelity simulations and materials synthesis, characterization, and fabrication to predict the performance of engineering design and deliver reliable technologies to our sponsors.

Our continued investment in high-quality research and development work, coupled with our ability to anticipate future needs, has been an extremely successful recipe for success. Through scientific and engineering innovation, Livermore is embracing its role as a broad national security laboratory and becoming the "go-to" institution for meeting the diverse needs of our sponsors and the nation.

■ Monya Lane is associate director for Engineering.

ADVANCED ENGINEERING DELIVERS MORE EXACT WEAPONS

Laboratory engineers exploit new material compositions, manufacturing techniques, and high-performance computing to develop munitions that minimize collateral damage and improve near-field lethality.

IN times of war, military personnel rely on an arsenal of tools, gear, and weaponry. This armament is necessary for protecting troops in combat as well as for mounting an offensive against the opposition. In the 21st century, confrontations are increasingly more likely to occur in urban areas rather than battlefields. Advanced weapons capabilities allow troops to maneuver in tight, often densely populated areas while minimizing inadvertent casualties or destruction of infrastructure.

Beginning in 2010, Lawrence Livermore partnered with the Air Force Research Laboratory (AFRL), the Air Armament Center (AAC), and a Department of Defense (DoD) manufacturer to deliver a highly effective, low-collateral-damage munition known as BLU-129/B to the U.S. Air Force. As part of this joint effort, which received support from the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics, the Laboratory leveraged its long-term investments in computational codes, computing and manufacturing infrastructure, and engineering expertise to develop the munition in record time.

"Typically, the process for getting a new munition into the field is 4 to 6 years," says Livermore's Kip Hamilton, who managed the BLU-129/B project. "We had the first prototype in 9 months, and the warhead was completely fielded in 18 months." Hailed as a success by DoD, the munition has been contributing to military actions—and saving lives—ever since.

The Laboratory develops a broad range of conventional (nonnuclear) weapons-related technologies for DoD, including those implemented in BLU-129/B. Many of these technologies get their start through the Joint DoD/Department of Energy (DOE) Munitions Technology Development Program (JMP). Started in 1985 under a memorandum of understanding between DoD and DOE, JMP creates advanced technologies to meet warfighter needs. Lawrence Livermore

PERFORMANCE

A multidisciplinary team of Livermore weapons physicists, computational and materials scientists, and precision engineers contribute to development work for low-collateral-damage munitions. By combining computer modeling and experimental analysis, they evaluate a wide range of parameters, such as carbon-fiber type, winding patterns, tow tension, epoxy mix ratio, and curing cycle, to determine the most effective attributes to meet a sponsor's requirements. This photo shows (from left) Greg Larsen, Dan Schumann, Bob Sanchez, Scott Groves, Jim Matthews, and Stevan Mays as they lay down carbon-fiber strands over a fixed mandrel to produce a warhead case.

is one of three National Nuclear Security Administration laboratories that conduct the program's critical work in collaboration with military agencies. "We work closely with military personnel and DoD researchers to stay at the forefront of future weapon capabilities," say Lara Leininger, program manager for the Livermore JMP. "If we are doing our job right, we are accurately anticipating the department's needs. Then when DoD is ready to move forward with a new technology, we've done all the initial, high-level research, and it can be transitioned to the DoD service laboratories quickly."

Over the last decade, weapon design efforts have focused on creating munitions that more effectively channel energy onto an intended target and reduce collateral damage from impact debris. In addition to warhead technology, JMP research focuses on firing systems, computational mechanics and materials modeling, warhead applications, technologies to penetrate hard targets, and energetic materials. Currently, scientists and engineers are exploring how other materials, including novel composite metal materials, could be applied to future munitions to enable more customized functionality.

Speeding Up Weapons Development

In 2001, JMP began a suite of projects to study how the attributes of metal-loaded explosives could be used to produce a class of munitions that combine very low collateral damage with increased (near-field) lethality on a target. "The way wars are fought now is vastly different than it was even 15 years ago," says Hamilton. "More consideration is given to protecting warfighters in close proximity to targets and to civilians not engaged in the fight. Developing more exact weapons that produce few if any fragments and therefore reduce collateral damage is important to war efforts."

The JMP projects have shaped advances in computational modeling and simulation that leverage the Laboratory's high-performance computing (HPC) resources.

BLU-129/B improves near-field lethality in combat zones while reducing collateral damage.

Sophisticated models provide a reliable and validated predictive capability that researchers can use to analyze material compositions and characterize an explosive's properties.

"By adapting first-principles physics codes to run in parallel on high-performance supercomputers, we have greatly improved our understanding of critical interactions that can affect weapons performance," says Mike King, who leads the Multidisciplinary Modeling and Simulation Group in Livermore's Engineering Directorate. "As a result, we have been able to increase the attainable strength of composites, develop better manufacturing processes to build stronger joints, and significantly enhance our knowledge of the lethal mechanisms of munitions."

At the most fundamental level, conventional munitions have an internal explosive and an outer metal case surrounding the explosive fill. Typically, the case is made from steel—a strong, ductile, and durable material. "Metal munitions work the same way they have since black powder was invented in the 9th century," says King. "Put an energetic material in a metal tube, blow it apart, and fragments are ejected outward."

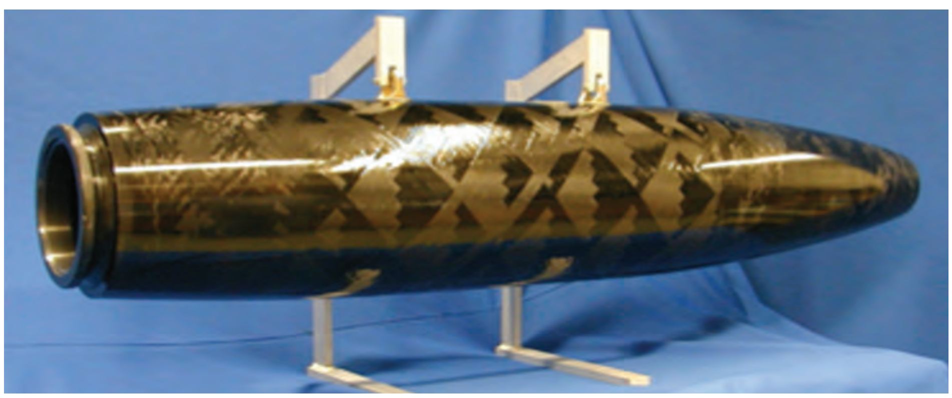
With munitions developed in the 20th century, a substantial amount of energy from the explosive goes into mechanically failing the case and accelerating the fragments. Fragments ejected from the case during detonation can travel long distances, often with lethal effects. As a result, the weapon can cause collateral damage outside the targeted area. JMP researchers began studying different material compositions with two goals in mind: eliminate the ejected fragments and improve the blast impulse at close range.

HPC resources were used to model a new type of explosive charge called multiphase blast explosive (MBX) and determine the appropriate volume needed for a munition. "Livermore's exploration of MBX performance properties began under JMP," says Dennis Baum, associate program director for Security Applications in the Laboratory's Weapons and Complex Integration Principal Directorate. Prior to Lawrence Livermore's involvement, researchers at AFRL and its High Explosive Research and Development Facility evaluated MBX as part of an effort to improve the effectiveness of existing penetrator weapons. Those exploratory tests revealed that a target subjected to an MBX charge experienced a greater impulse of energy than did targets subjected to other explosive compositions. "MBX fundamentally changed the rate at which lethality decreases with distance from the munition," says Baum. "It was the key enabling technology that eliminated the need for a metal case."

Livermore's growing expertise in modeling and fabricating composite materials such as carbon fiber was an important part of the Air Force partnership. Composites are made from two or more chemically and physically different materials that when combined can be "tailored" to deliver specific effects. To create a munition that could meet the sponsor's low-collateral-damage requirements, the project team created a composite outer shell to use with the novel MBX fill.

Carbon-fiber composite is a well-studied material and is widely used in industrial applications, such as in aircraft and automobile components. In certain configurations, it can be stronger than steel at a fraction of the weight. The composite's precise characteristics can also be controlled by the pattern in which the fibers are wound. A carbon-fiber composite case has the strength to withstand penetration into concrete structures and produces no lethal fragments on detonation. The total system weight is also greatly reduced.

The Laboratory's HPC capabilities help researchers optimize designs for carbon composite cases and meet the



Carbon-fiber composite cases, such as the one shown here, produce no lethal fragments when the munition is detonated. They also weigh much less than conventional steel cases.

sponsors' stringent operational and performance requirements. Computing codes model fundamental material properties and simulate composite performance under extreme conditions, for example, assessing material behavior up to and after failure. "As part of the JMP effort, we are exploring the basic failure mechanisms of composites under compression so we can design stronger materials," says King.

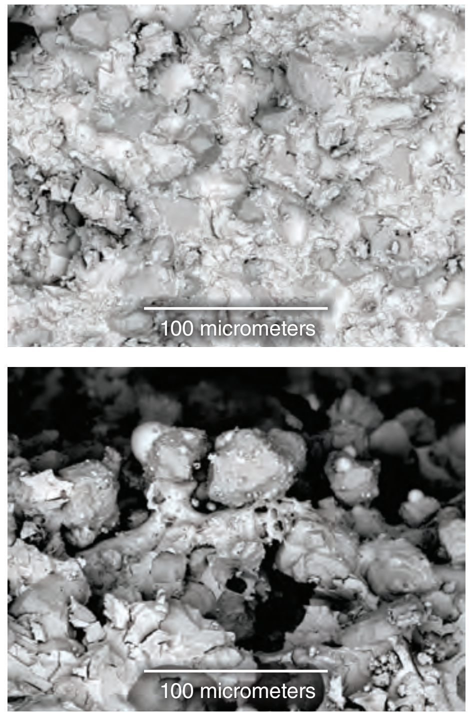
Carbon-fiber composite is strong, but it can fracture when compressed. This type of failure, known as microbuckling, occurs when the fibers locally buckle and then form kink bands. Computational tools such as the carbon micromechanical model serve as a test bed for subjecting virtual materials to an array of external conditions before experiments are run to confirm the results.

Simulations also greatly reduce the cost and time needed to design a weapon. "In the 'old' days, we would build a prototype, test it, and revamp it based on the results," says Hamilton. "We had to complete many cycles of testing before we had a production-ready component. Our advanced modeling and simulation capabilities reduce the time needed to determine the final design specifications for munitions. For example, 95 percent of the final design for BLU-129/B was done through modeling and simulation." King and Hamilton note that even with advanced computing capabilities, experimental testing is still needed to validate models. Says King, "Experiments provide an affirmation that new munitions will perform exactly as intended."

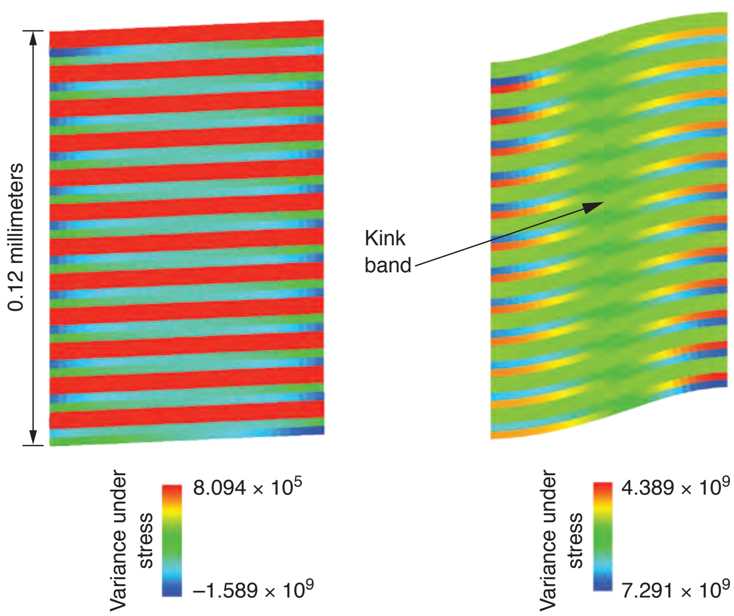
Weapon Functionality on the Fly

In a separate JMP project, Livermore scientists and engineers are developing new metal material compositions to further tune weapon effects. "We are working on conceptual technology that could be applied to future munitions," says Livermore materials scientist and engineer Mukul Kumar, who leads this project. His team is studying multicomponent materials with microstructures that exploit the different responses of each component. The team's goal is to fabricate novel material compositions that customize fragmentation of a warhead case. "We intend to develop robust, affordable, and well-understood materials by properly engineering their microstructure to produce predictable fragments," says Kumar. "Essentially, we are enabling fragmentation by design."

Metal cases for warheads generally fragment in one of two ways: naturally or in a controlled manner. Natural fragmentation, which has been extensively studied, yields a random distribution of particle sizes. In controlled fragmentation, the case is mechanically scored to produce a particular size distribution. Developing designer, engineered case materials with "tailored lethality" for natural fragmentation (including materials that produce no fragmentation) requires knowing how a material's structure and properties influence case breakup. Says Kumar, "To determine how a material's microstructure affects its dynamic properties, scientists and engineers must understand both the



Micrographs reveal microstructural details of a composite material (top) before and (bottom) after compression tests. Light regions are the matrix material, and dark regions are metal designed for tailored fragmentation. After compression, the microstructure clearly shows that the matrix material was removed.



Results from a carbon micromechanical simulation illustrate how compression causes a material's fibers to buckle and form kink bands.

fundamental physics of the natural length scale in fragmentation and the coupling of the microstructure to these conditions."

As a proof of concept, Laboratory investigators Kyle Sullivan and Joshua Kuntz in the Physical and Life Sciences Directorate are creating and testing powder composites of metals intended to become fragments combined with a matrix material. "We chose materials that have the strength, toughness, and ductility needed for the applications we are interested in," says Kumar.

Sullivan worked with physicist Damian Swift on laboratory-scale experiments to help validate powder metallurgy techniques and material response—spalling or cracking, for example—of microstructures across a broad range of material volumes. The tests confirmed that the engineered microstructures respond as expected. The matrix material can be manipulated, leaving behind high-density particles. Understanding how metallic composites transform under these conditions is key to developing a composition and microstructure that deliver a desired fragmentation response.

"Conducting lab-scale tests as preliminary experiments has been valuable," says Kumar. "They can be readily fielded and provide the conditions necessary to validate our compositions. We can also easily remove samples for postshot analysis, and the throughput is excellent, allowing us to run 5 to 10 samples a day." If initial tests confirm the predicted behavior, another set of experiments will be conducted on a larger scale to perfect the composite. These final tests will determine whether the material developed is viable for fragmenting a case as designed. Kumar says, "Tailoring the fragmentation response of warhead case materials will enable a broad range of selective effects munitions."

Modeling and simulation efforts run parallel to the characterization and testing of these novel microarchitectures. The first objective of the computational work is to build a robust framework for performing calculations on fragmenting metals.

In 2012, Livermore researchers James Stölken and Matthew Barham simulated a particular type of steel and used the resulting data to determine the constitutive parameters for Livermore hydrocodes. The experimental work, from an earlier JMP-funded collaboration with the U.S. Army Armament Research, Development, and Engineering Center and Sandia National Laboratories, probed the effect of a systematic variation in a material's microstructure. "This work has served as a terrific test bed for simulation capabilities," say Kumar. The same tools are being used to study the metal powder composites in the current JMP project. "These tools may one day enable us to computationally design material microstructures and architectures for specially tailored response in munitions."

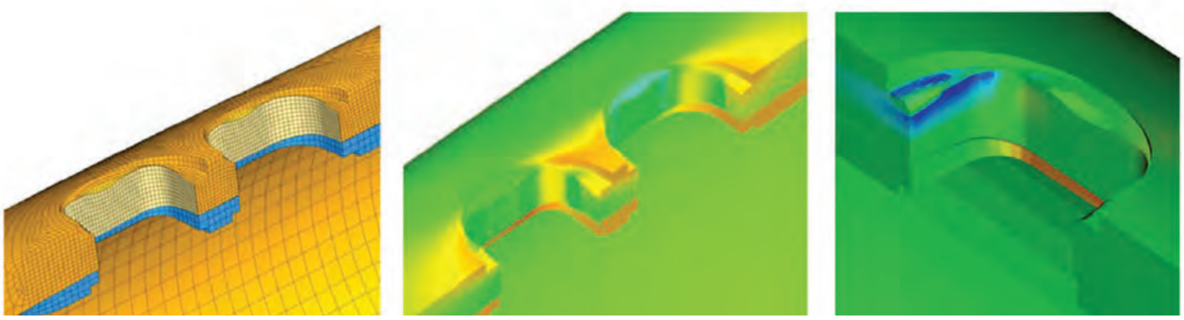
Alternative processing routes and material fabrication are also being evaluated. In the future, advanced additive manufacturing techniques could enable an entirely new class of material structures with improved performance. (See *S&TR*, March 2012, pp. 14–20.)

Target Precisely Acquired

When developing a munition, computational and weapons engineers must be familiar with the system requirements designated by the sponsor. Engineers must also assess the potential limitations, including whether possible contaminants could affect a munition's operability and what level of damage could ultimately cause it to fail. Mitch Moffet, a Livermore weapons engineer says, "We have to deliver exactly what the sponsor wants and needs, which requires a thorough understanding of how the weapon can and will perform." Computational and weapons engineers must work in tandem throughout the design process to ensure that what is created in theory through models and simulation can actually be built. Adds Moffet, "The two disciplines iterate back and forth until we have a workable design."

New munitions must be compatible with existing guidance systems, which have become exceedingly accurate in recent years and have made it possible to build more effective weapons. "Old munitions, such as the ones used in World War II, are like a shotgun. They are designed to work even when a target cannot be pinpointed directly," says King. "With precision guidance, warfighters aren't limited to using weapons with a large range of effectiveness because the laser can more accurately acquire a target."

The ability to couple sophisticated guidance systems with weapons that have a more accurate lethal footprint has been profound. By making the effects of weapons commensurate with their



Supercomputing models and simulations allow engineering features in the composite case to be optimized to maximize strength and performance.

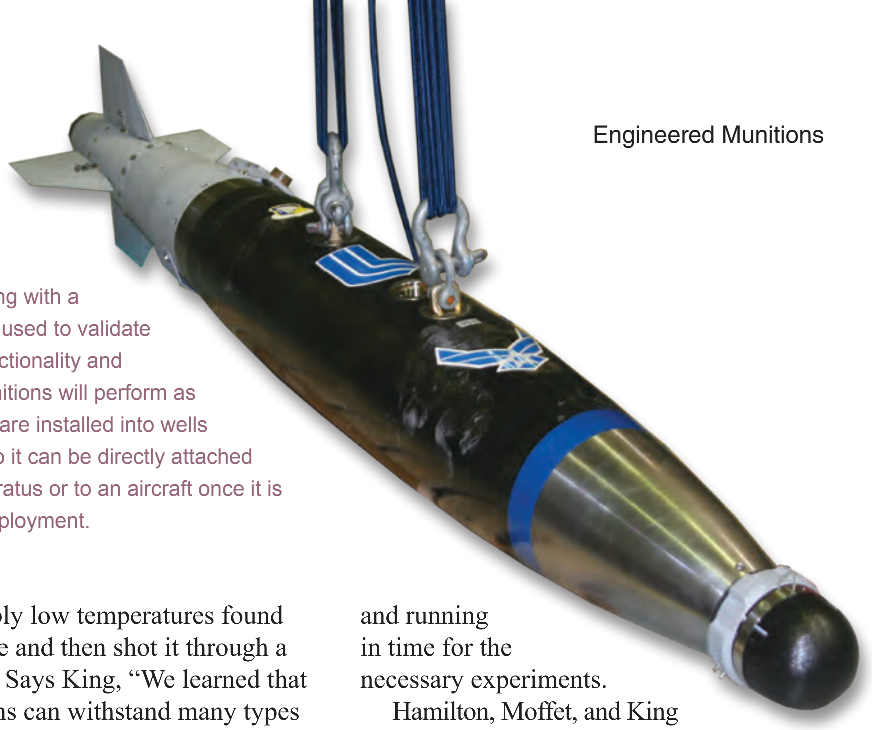
accuracy, engineers are providing the military with highly efficient and effective munitions for fighting in close quarters.

A Win–Win Situation

The JMP–Livermore partnership has a proven track record for executing exceptional weapons science in service to the nation. BLU-129/B is an important example of this tradition. One issue that has plagued munition development is the speed at which weapon technology is transferred from government to industry and thus from a laboratory to the military. Typically, researchers design and test a munition and transfer the specifications to a manufacturer, whose team redesigns the munition based on the detailed parameters. These new revised units must also be tested, increasing costs and delaying delivery of the final system.

The seamless transition from BLU-129/B concept to deployed munition illustrates the benefits of a close collaboration with the sponsor and the manufacturer. "Throughout the entire program, we included the manufacturer in the warhead development and assembly processes to ease the transition from Livermore's warhead prototypes to industrial production," says Hamilton. The Livermore team designed, built, and provided the manufacturer with most of the tooling required to assemble the system. As a result, the production units were assembled using the same tools and methodologies that the Laboratory team put together during the project's development phase.

Prior to assembling production units of BLU-129/B, Livermore collaborated with AFRL to test the munition's durability and reliability. Researchers subjected the munition to a complete battery of tests, including those for flight safety. In one set of experiments, a bomb dropped from significant height came out unscathed, demonstrating its safety. Another experiment chilled a munition to the incredibly low temperatures found at high altitude and then shot it through a concrete wall. Says King, "We learned that these munitions can withstand many types of physical hardships and still function as designed."



Vibrational testing with a modal device is used to validate guidance kit functionality and ensure that munitions will perform as designed. Lugs are installed into wells on a munition so it can be directly attached to the test apparatus or to an aircraft once it is approved for deployment.

Another benefit of the LLNL–AFRL–AAC partnership is that BLU-129/B is a government-owned design. As a result, the contract to manufacture production units can be put up for bid to other industrial companies as a means to reduce production costs for the military. Overall, the technology-transfer process was a win–win for the armed services: production units function as designed, and the system is cost-effective.

The BLU-129/B project is a prime example of what can be achieved when multidisciplinary teams from several institutions work toward a common goal with strong support from each organization's management and from the project's sponsors. "To meet the needs of this time-critical mission, Livermore's senior management ranked the project as high priority and supported the team throughout the design and development process," says Hamilton. "We were able to tap systems engineering expertise to rapidly assemble key personnel across multiple engineering divisions and implement needed facility capabilities."

He recalls that at one point, the team had to resurrect an old press from storage to test compression parameters for the munition. "It was the only press that could provide the pressures needed for the test." With a little elbow grease and engineering know-how, the team had the press up and running in time for the necessary experiments.

Hamilton, Moffet, and King agree that the Laboratory's partnerships with its sponsors and industry plus the tenacity and vision of the entire development team were important for the project's success. As a result, the military could deploy a new unit for flight certification in the same calendar year that the project started. "We contributed to saving lives in the combat zone in 18 months," says Moffet. It was an impressive feat by any standard, and one that is enabling warfare to be fought with better precision while helping to protect soldiers and innocent civilians.

The success of BLU-129/B serves as a blueprint for future research, technology transfer, and engineered munitions at the Laboratory. Says Leininger, "When we combine this blueprint with the continuing development of munitions technologies in JMP, the possibilities for transitioning advanced munitions to meet warfighter needs is unlimited."

—Caryn Meissner

Key Words: Air Armament Center (AAC), Air Force Research Laboratory (AFRL), BLU-129/B, carbon fiber, composite material, Department of Defense (DoD), Department of Energy (DOE), Joint DoD/DOE Munitions Technology Development Program (JMP), multiphase blast explosive (MBX), munition, weapon.

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ON THE PATH TO IGNITION

National Ignition Facility experiments produce new states of matter as scientists close in on creating the conditions required to ignite fusion fuel.

AMONG the most challenging scientific quests over the past 50 years has been the international effort to create, in a laboratory setting, a miniature "star on Earth." The goal of this endeavor is to surpass the extreme mix of temperature, density, and pressure at the center of the Sun and generate conditions in which hydrogen fusion reactions can start and sustain themselves, thus creating a fusion fire in the laboratory. The ongoing fusion reaction in the Sun's center provides all the energy needed for life on Earth. Replicating this sustained reaction in a laboratory requires conditions that are even more extreme: temperatures in the tens of millions of degrees, pressures hundreds of billions of times Earth's atmosphere, and a density of burning matter that is more than 100 times the density of lead.

In their quest to bring "star power" to Earth, researchers at the National Ignition Facility (NIF) have worked over the past 18 months to produce states of matter never before achieved in a laboratory setting. Using all 192 beams of the giant laser, experimenters are generating temperatures and densities inside an imploding, peppercorn-size capsule of frozen hydrogen isotopes (deuterium and tritium, or D–T) that when compressed to the diameter of a human hair will sustain fusion burn.

Edward Moses, principal associate director for NIF and Photon Science and leader of the fusion program effort, says, "The ultimate goal of these experiments is to ignite a self-sustaining burn wave of fusion fuel, producing more energy than is delivered to the target—an event called ignition." NIF researchers are moving ever closer to achieving ignition and fulfilling the vision of early fusion pioneers such as former Laboratory Director John Nuckolls. Shortly after the laser's invention in 1960, Nuckolls conceived of using the x rays generated by a powerful laser pulse to fuse hydrogen isotopes, convert matter into energy (as in Einstein's famous equation, $E = mc^2$), and thereby liberate more energy than is delivered by the laser pulse.

"NIF was designed to be the world's largest laser," says NIF chief scientist John Lindl. "In fact, it now operates as such. We have known from the outset that the energy it delivers does not give us a large margin of performance to achieve ignition. Everything that occurs during the implosion of hydrogen fuel must be nearly perfect."

Lindl notes that significant progress has been made since precision experiments began in May 2011, as part of the National Ignition Campaign (NIC). (See the box on p. 12.) He attributes that success to the heroic efforts of the entire NIF staff. "In all areas of the organization—lasers, diagnostics, cryogenics, and operations—people have worked incredibly hard and with incredible skill. As a result, we have made huge advances in technology, materials, and scientific understanding. We have come a long way and routinely achieve environments that are extreme by any measure."

Indirect Drive Heats the Fuel

To achieve the extreme conditions required for fusion, NIF's 192 laser beams are focused into laser entrance holes at each end of a 1-centimeter-long cylindrical target, called a hohlraum. The laser beams irradiate the interior surface of the hohlraum, raising the interior temperature to more than 3 million degrees Celsius. At these temperatures, the hohlraum works much like an oven, radiating x rays into its own interior. The x rays in turn irradiate the plastic shell of the fuel capsule mounted in the hohlraum's center, ablating the surface and causing the capsule to implode through a rocketlike reaction.

X-ray and neutron emission images from ignition experiments show that the interior volume of the capsule collapses by almost a factor of 100,000, heating and compressing the frozen D–T ice layer, the fuel for ignition, lying just inside the outer plastic layer. In experiments to date, the resulting hot center, called the hot spot, reaches temperatures of nearly 40 million degrees Celsius with densities of 50 to 100 grams per cubic centimeter (5 to 10 times the density of lead) and pressures 150 to 200 billion times Earth's atmosphere. These conditions are hotter and nearly as dense as those in the center of the Sun.

The hot spot is surrounded by a region containing about 90 percent of the fusion fuel, which has a density of 600 to 800 grams per cubic centimeter at a temperature of 1 to 2 million degrees Celsius. The fuel's density is about 3,000 times the initial density of the frozen D–T layer—well in excess of that in the Sun's center and by far the highest

The National Ignition Campaign

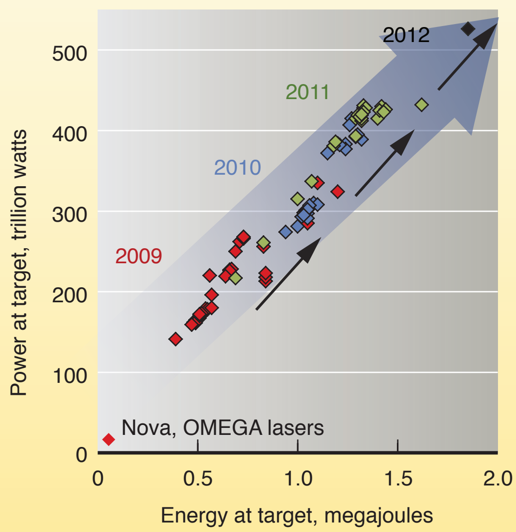
Ignition experiments on the National Ignition Facility (NIF) began as part of the National Nuclear Security Administration's (NNSA's) National Ignition Campaign (NIC). This campaign, which began in 2006 and ended September 30, 2012, had two principal goals: transition NIF to routine operations as the world's preeminent high-energy-density user facility for the nuclear weapons programs, fundamental science, nonproliferation, and other national security purposes and develop the capability to study and achieve ignition on NIF. The campaign involved the participation of Sandia and Los Alamos national laboratories, General Atomics, and the Laboratory for Laser Energetics at the University of Rochester. Other key contributors included the Massachusetts Institute of Technology, Lawrence Berkeley National Laboratory, Atomic Weapons Establishment in England, and the French Commissariat à l'Énergie Atomique.

Following completion of NIF construction in March 2009, researchers focused on installing, qualifying, and integrating the facility's many systems as well as developing the experimental platforms necessary to study and control, with adequate precision, the key processes necessary for achieving ignition. (See *S&TR*, September 2012, pp. 14–21.) Precision implosion-optimization experiments using these platforms steadily increased the pressure in the frozen hydrogen fuel from about 1,000 terapascals (or nearly 10 billion times atmospheric pressure) in the early implosions to currently about 15,000 terapascals, achieving densities in excess of 600 grams per cubic centimeter or about 60 times the density of lead. Although the pressures achieved are approaching those in the center of the Sun and are by far the highest ever achieved in the laboratory, they remain a factor of two to three below those needed for ignition.

Over the course of NIC, a large body of scientific knowledge and major new experimental, diagnostic, and target manufacturing capabilities were developed and validated. NIF scientists and engineers steadily increased the laser's energy and power, culminating on July 5, 2012, when the system's 192 beams delivered more than 1.8 megajoules of ultraviolet light (in excess of 50 times more energy than any laser has demonstrated) and more than 500 trillion watts of power to the center of the target chamber. (See *S&TR*, September 2012, p. 2.) The combination of energy and power, along with the precision of laser beam pointing and power balance of all the beams, met the NIC specifications. International review committees have agreed that the laser has proven exceptionally reliable, durable, precise, and flexible in accommodating the unusually diverse needs of various research groups.

An NNSA report to Congress in December 2012 stated that "The NIF laser performed reliably and with great precision and executed thirty-seven cryogenic implosion experiments. Power and energy have exceeded initial design specifications. Target quality is superb, and diagnostics have been developed that are returning experimental data of unprecedented quality."

The report added, "The pursuit of ignition and high fusion yields in the laboratory is a major objective of the SSP [Stockpile Stewardship Program] and ICF [Inertial Confinement Fusion] Program and is a grand challenge scientific problem that tests our codes, our people, our facilities, and our integrated capabilities."



Scientists have steadily raised the power and energy levels at the National Ignition Facility (NIF) since it was completed in September 2009. On July 5, 2012, the laser system's 192 beams delivered more than 1.8 megajoules of ultraviolet (3-omega) light and more than 500 trillion watts of power to a target. This unprecedented combination of energy and power met NIF's original design specifications.

density ever achieved in laboratory experiments.

The goal of current experiments is to increase the hot-spot density by another factor of three at about the same temperature already being achieved. Under these conditions, the fusion reaction rate would be sufficient to generate ignition, or burn conditions. The precursor step to ignition is attaining measurable alpha heating, in which the helium nuclei (alpha particles) produced by the fusing of deuterium and tritium nuclei deposit enough kinetic energy to increase the fuel's temperature well above that produced by the laser-generated implosion alone. "Alpha-particle heating is required for sustained fusion burn and the release of more energy than was necessary to initiate the reaction," explains Lindl.

Alpha heating can only happen when the hot-spot fuel is dense enough and has a sufficient radius to capture the alpha particles and absorb their energy. For the first time in any laboratory, NIF experiments are routinely producing fuel conditions sufficient to stop fusion-produced alpha particles, a critical requirement for self-heating of fusion fuel. In the better-performing implosions to date, more thermonuclear energy is produced from the hot spot than is delivered by compression heating from the laser energy alone. About one-fifth of this hot-spot energy is in the form of alpha particles. Calculations indicate that the alpha-particle yield must be about a factor of 10 higher to initiate ignition and a self-sustaining burn wave that starts in the hot spot and propagates into the surrounding main fuel, a process Lindl compares to lighting a fire with a match.

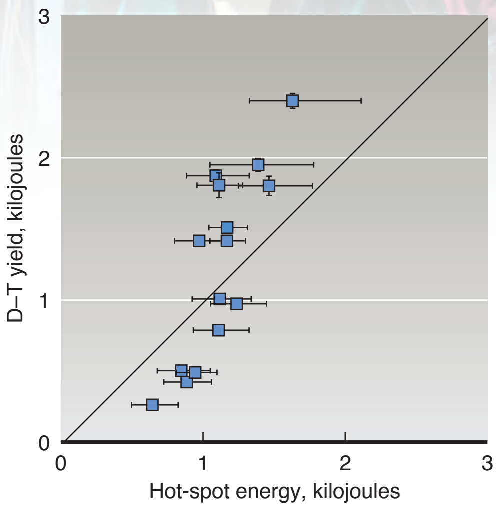
Perfecting Symmetry

Implosion velocities greater than 300 kilometers per second (or nearly 700,000 miles per hour) and a uniformly spherical implosion are essential for producing the fuel conditions needed for ignition. The hohlraum must be heated to 3 million degrees Celsius, and the flux of x rays streaming onto the fuel capsule must have a uniformity of better than 1 percent. Laser light thus needs to be absorbed by the gold hohlraum in a precise and prescribed manner. Achieving the required precision is challenging because of instabilities that inevitably occur when intense laser light interacts with the hot plasma, filling the hohlraum.

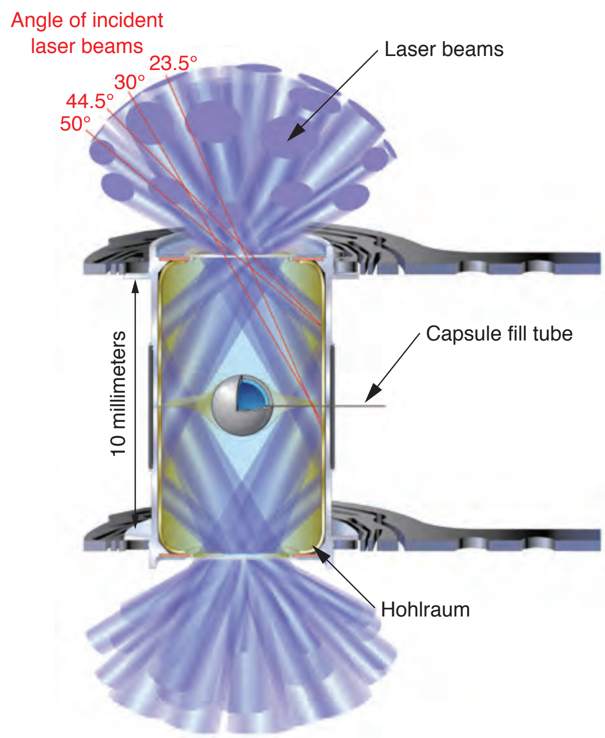
This complex, interactive laser propagation phenomenon is particularly difficult to model because the laser itself produces the hot plasma in the hohlraum. Codes developed to simulate laser–plasma interactions are at the edge of the Laboratory's current calculational capabilities. They have a voracious appetite for the computing capacity available on Livermore's high-performance machines.

Models describing hohlraum physics must accurately simulate a host of intricate processes. For example, laser light passes through the laser entrance holes and interacts with the ions and electrons that make up the plasma. Plasma energy heated by the laser is conducted away from the absorption regions. Absorbed light is subsequently converted into x rays that flow within the hohlraum and are absorbed into the fuel capsule's ablator layer. Codes must also model the physics during capsule implosion and the thermonuclear burn of the D–T fuel.

When NIC began, models of hohlraum physics had been developed and tested using the OMEGA laser at the University



NIF researchers are continuing to work on elevating the hot-spot temperature and density through increased alpha heating to improve deuterium–tritium (D–T) yield. The yield attained in current experiments is about 50 times greater than that achieved on the first cryo-layered experiment in 2010 and is within a factor of 5 to 10 of the yield needed to initiate ignition.

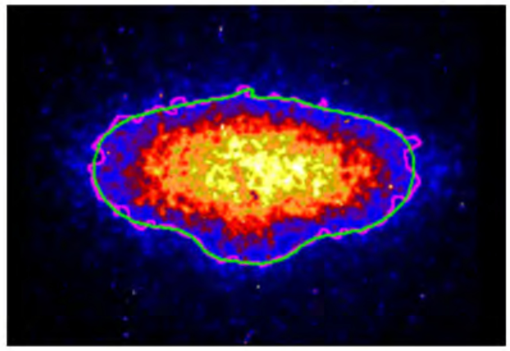


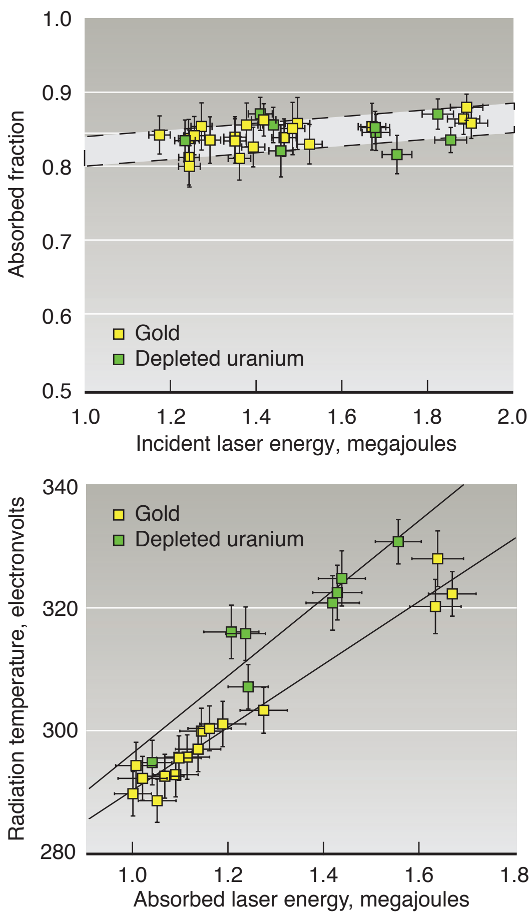
NIF laser light enters the two laser entrance holes to form an inner cone that illuminates the hohlraum wall near the equator of the capsule. An outer cone is also formed that illuminates an area of the wall closer to each laser entrance hole. The outer cone is composed of two subcones, one at 50 degrees and one at 44.5 degrees. The two inner subcones enter at 30 and 23.5 degrees.

of Rochester and, before that, Livermore's 10-beam Nova laser. Those experiments were performed on much smaller targets, using 50 to 100 times less laser energy than NIF routinely produces. Some researchers were concerned that these experiments and, consequently, the models would not be applicable when scaled to NIF. To address this concern, the NIF team tested and improved the models as NIC experiments gathered data at higher energy and on larger targets.

During an ignition experiment, laser light enters each laser entrance hole in the form of two cones. An inner cone containing one-third of the energy travels at a low angle into the hohlraum and illuminates the wall near the equator. An outer cone containing two-thirds of the energy enters at a high angle and illuminates an area of the hohlraum wall closer to each laser entrance hole. Each inner and outer cone is composed of two subcones. Beams forming the outer cone enter the top and bottom laser entrance holes at angles of 50 and 44.5 degrees with respect to the hohlraum's vertical axis. The inner beam energy is split equally between 30 and 23.5 degrees. This illumination pattern ensures that the x-ray drive on the target remains uniform in space and controllable in time.

Experiments show hohlraums absorbing about 85 percent of the laser energy. Losses are caused by instabilities that occur when laser light interacts with plasma ions and electrons emanating from the gold hohlraum, with the outer plastic layer of the fuel capsule, and with helium ions inside the hohlraum. Most interactions are unwelcome because they scatter laser light, thereby interfering with the uniform x-ray field needed to evenly compress the capsule. Interactions can also accelerate plasma electrons to energies high enough to preheat the capsule and make compression more difficult. The main type of laser–plasma interaction is stimulated Raman scattering on the inner beams, which produces energetic, superhot electrons.





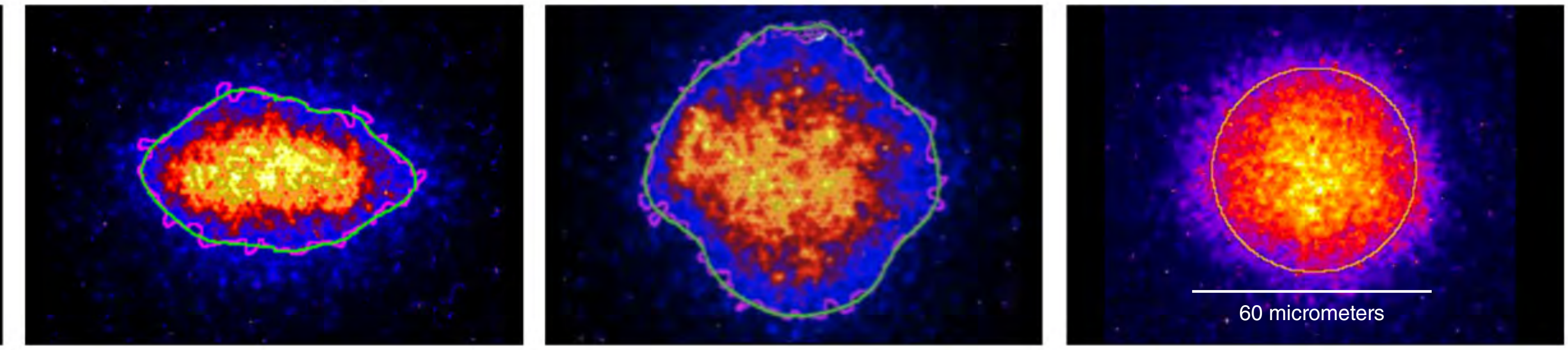
(top) Hohlraums, whether manufactured from gold or depleted uranium, absorb about 85 percent of the laser energy, a percentage that is nearly independent of laser energy. The shaded band shows the best fit to the data with ±1 standard deviation. (bottom) In contrast, hohlraum radiation temperatures rise with increased laser energy, as expected, and higher temperatures are achieved with depleted uranium compared with gold.

Taming Laser–Plasma Instabilities

The first NIF hohlraum energetics shots fielded from 2009 to 2010 yielded critical data for efforts to control laser–plasma instabilities. Some of the earliest results were not consistent with predictions from the standard model experimenters had been using with the less-energetic lasers. The NIF shots experienced more stimulated Raman scattering and much cooler plasma temperatures than predicted as well as a tendency toward pancake-shaped implosions (instead of the desired round shape). In addition, the x-ray drive on the fuel capsule differed from predictions.

The standard model was originally developed in the 1970s—an era when computer resources were much less capable than the current generation of supercomputers at Livermore. "Laser–plasma interactions such as stimulated Raman scattering are difficult to model, and to predict them accurately requires a correct notion of the plasma conditions," explains physicist Mordy Rosen. "Although we knew the standard model had shortcomings, its results were considered conservative."

In 2010, Rosen and colleagues developed the high flux model (HFM), which contains two important advances. It more realistically accounts for the



A series of micrographs shows the dramatic improvements (from left to right) made in implosion symmetry on the first four ignition experiments conducted September 2–5, 2009. The pancake-shaped implosions were inconsistent with predictions from the guiding standard model. Scientists used crossbeam energy transfer to make small adjustments in wavelengths and redirect energy from outer to inner cone beams. The technique, together with other adjustments, results in much more spherical implosions.

complex atomic physics occurring in the hot, partially ionized gold atoms from the hohlraum wall. It also incorporates a modified model for the flow of heat carried by the plasma electrons. The new model accurately predicted a much cooler hohlraum plasma (25 million degrees Celsius compared with the 40 million predicted by the standard model). This cooler plasma helped plasma physicists Denise Hinkel and Ed Williams explain the spectrum and level of the Raman light found in the data. HFM also predicted a higher flux of x-ray emission, as was indeed observed flowing from the hohlraums through the laser entrance holes.

In addition, HFM accurately predicted the unexpected pancaking of the fuel capsule that occurs because the outer beams convert laser light to x rays more efficiently than the inner beams. These x rays shone more brightly on the poles of the capsule, driving it toward a pancake shape instead of a uniformly round sphere. The cooler and denser plasma absorbed more light from the inner beams, preventing those beams from penetrating into the hohlraum's midplane. As a result, the inner beams could not provide enough drive on the central region of the hohlraum to counter the outer beams' drive on the pole regions. A pancake-shaped implosion thus ensued.

The NIC team took the unusual step of using laser–plasma interactions to overcome the uneven distribution of laser light on the hohlraum walls. The researchers used a technique called crossbeam energy transfer that can occur in plasma when two or more high-power lasers traveling in different directions overlap. This phenomenon permits redirecting energy between the outer and inner cone beams where they overlap at each laser entrance hole. Controlling the shift in the energy balance of the two cones requires adjusting the color, or wavelength, of beams forming the outer cone by 0.6 to 0.9 nanometers to provide 25 percent more power to the inner cone. "We had always assumed we would have to minimize crossbeam transfer," says physicist Debbie Callahan. "Then we realized it could be a tool to improve implosion symmetry."

Says Lindl, "Until recently, there was never a time when plasma phenomena could help us; it usually made life more difficult. We could try turning up the energy on the inner beams, but that approach would drive the laser harder. NIF works more efficiently when all beams have the same power. Instead, we shifted energy from the outer to the inner cones. NIF was built with the capability to adjust the wavelength of internal and external beams to minimize crossbeam transfer. Adjusting the wavelength separation to control symmetry wasn't part of the original NIF plan, but it works beautifully." With these insights, researchers are working to further reduce laser–plasma interactions.

Successful experiments in 2009 prompted scientists to add another refinement. They adjusted the relative wavelengths on the 23.5- and 30-degree inner beams by 0.1 nanometers to more precisely control the asymmetry as seen from the poles of the capsule in the hohlraum (when viewed up or down the hohlraum's axis).

The final arrangement involves first transferring energy from the 44.5- and 50-degree beams into the 23.5- and 30-degree beams. Energy is then transferred from the 30-degree beam to the 23.5-degree beam deeper into the hohlraum plasma, where only these beams continue to overlap. Together, the energy-transfer measures produce a much brighter beam that propagates more deeply into the hohlraum's center. For this pioneering work, a team of NIF researchers earned the American Physical Society's 2012 John Dawson Award for Excellence in Plasma Physics Research.

Adjusting the power levels among the subcones controlled only one aspect of implosion symmetry. Another aspect was achieved by more precisely pointing beams at spots on the hohlraum walls. Additionally, the team made small design changes to the hohlraum geometry. A somewhat shorter and wider hohlraum allows the inner beams better access to the waist region. Together, the more-precise beam pointing, crossbeam energy transfer, and modified hohlraum dimensions are key steps for meeting the stringent uniformity requirements of 99-percent capsule radiation flux to achieve ignition. Because HFM predictions have been consistent with various experimental observations, the model allows researchers to better understand hohlraum performance and the role of laser–plasma interactions.

Lindl cautions that optimizing implosion symmetry is not yet complete. For example, the D–T fuel layer surrounding the hot spot can have a different shape than the hot spot. The NIF team is currently developing techniques such as Compton radiography (an x-ray shadowing technique) to provide data on the D–T layer's shape at peak compression. Early results show that the position of the outer beams on the hohlraum wall is not yet optimal for ensuring a symmetric implosion. Upcoming experiments will focus on improving the D–T layer's shape.

Pulse Shape of Four Precise Shocks

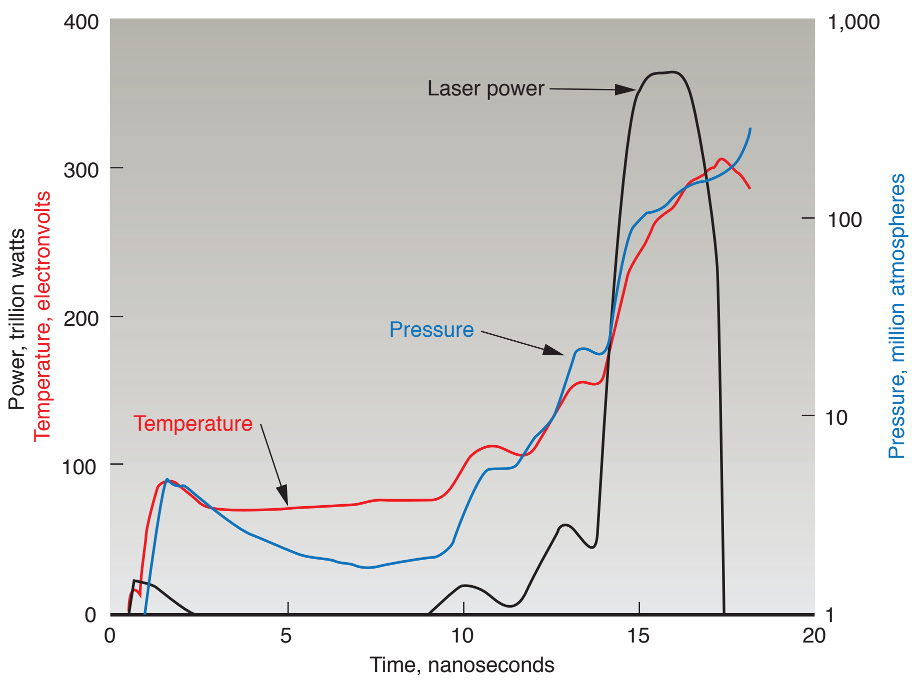
A nearly perfect x-ray drive on the outer plastic shell is only one essential element of ensuring ignition. In addition, the laser pulse must be carefully shaped to send a precisely timed series of shocks through the frozen D–T layer. The timing is such that the shocks overtake each other soon after they travel into the D–T gas comprising the very center of the fuel capsule.

"If we merely hit the capsule with the power required to generate the 10-terapascal pressure needed to achieve the desired implosion velocity, the shock from that pressure would generate too much internal heat and decompress the frozen D–T layer," says Lindl. "To obtain high velocity without significant shock heating, we must gradually increase the pressure. The NIF ignition pulse achieves the desired pressure of 10 terapascals in a sequence of four weaker shocks."

The goal of ignition shock-timing experiments has been to precisely set the power levels for each of the four shocks, which together create an overall pulse lasting about 20 nanoseconds. The pulse consists of an initial small shock (called a picket), followed by a relatively low-energy but important 9-nanosecond-long trough to maintain a constant first-shock velocity in the capsule. Second, third, and fourth shocks at increasing power are followed by a 3-nanosecond peak power pulse, which provides most of the drive for final acceleration of the shell. The symmetry of the imploded core (hot spot) is affected by the symmetry of each shock, but it is most sensitive to the initial picket and the x-ray drive produced by the final peak power pulse.

Physicist Harry Robey notes that each shock wave propagates through the capsule ablator and compresses the fuel layer. The first three shocks are adjusted to merge just after passing through the D–T layer. "We want these three shocks to merge at one time in a single radial location inside the capsule," says Robey. If they are not spaced correctly (and at ±50 picoseconds, or 50-trillionths of a second), the D–T fuel layer will not reach the required density at the end of the implosion. A correctly timed fourth shock, designed to overtake the first three shocks after they coalesce, is critical for keeping the fuel at maximum compression.

Experiments to measure the strength (velocity) and timing of these shocks are conducted in a keyhole target platform. Keyholes have a cone inserted through the side of the hohlraum wall and into a capsule filled with cooled liquid deuterium—an excellent substitute to the D–T ice layer. These experiments use the velocity interferometer system for any reflector (VISAR), where the shock in the plastic shell or the surrogate fuel reflects the



Achieving ignition requires a 20-nanosecond-long laser pulse that sends a carefully timed series of shocks to efficiently compress the fuel capsule. As each shock passes through the capsule, the fuel is further compressed. The 3-nanosecond peak power pulse that follows this sequence provides most of the drive for final acceleration of the capsule.

A NIF technician holds a keyhole target attached to equipment that is part of the cryogenic cooling system. Keyhole experiments measure the strength (velocity) and timing of the four shock waves from the laser pulse as they transit the capsule. For these experiments, a cone is inserted through the side of the hohlraum wall and into a capsule filled with cooled liquid deuterium. The inset shows the keyhole cone and capsule without a hohlraum around them.

VISAR laser. The instrument then precisely records the timing of all four shocks.

Ignition Ahead

Lindl notes that scientists have already achieved the required x-ray drive temperature, hot-spot shape, and shock timing, and they have nearly attained the needed implosion velocity. However, challenges remain. Densities in the D–T layer must reach 1,000 grams per cubic centimeter, somewhat higher than the 600 to 800 grams per cubic centimeter achieved in current experiments. Likewise, hot-spot pressures are a factor of two to three lower than those required for ignition. Looked at another way, because the measured hot-spot temperatures are close to those needed to reach ignition, the hot-spot density is a factor of two to three lower than required.

Recent experimental evidence also indicates that the achieved pressure is insufficient because the imploding D–T fuel layer surrounding the hot spot is not as spherical as required. "We believe that understanding and controlling three-dimensional departures from spherical implosions is a critical milestone on the path to ignition," says physicist John Edwards, associate program leader for Inertial Confinement Fusion in the NIF and Photon Science Principal Directorate. Radiography of the D–T fuel at peak compression will better record the hot-spot shape and distinguish among different mechanisms that can affect the degree and uniformity of compression. When NIF's Advanced Radiographic Capability goes online, it will generate a much brighter source of x rays for Compton radiography than can be obtained with the standard NIF beams. (See *S&TR*, December 2011, pp. 12–15.)

"NIF continues to make outstanding progress toward the goal of ignition," says Lindl. "The laser, diagnostic systems, target design and fabrication, and round-the-clock operations are producing data of unprecedented quality."

"Discovery science is the exploration of the unknown," continues Lindl. "Ignition remains a grand scientific challenge that requires unprecedented precision from the laser, diagnostics, targets, and experiments. We can't say exactly when we will achieve ignition, but we have made tremendous progress and have developed an exciting experimental plan to take us the rest of the way."

—Arnie Heller

Key Words: Advanced Radiographic Capability, alpha heating, crossbeam transfer, high flux model (HFM), hohlraum, ignition, National Ignition Campaign (NIC), National Ignition Facility (NIF), stimulated Raman scattering, velocity interferometer system for any reflector (VISAR), wavelength tuning.

For further information contact John Lindl (925) 422-5430 (lindl1@llnl.gov).

New Mechanisms for Regulating Bone Formation

PROTEINS participate in virtually every process that takes place in a cell, yet the majority of functional elements in the human genome do not code for proteins. Once thought to have no biological function, certain non-protein-coding DNA segments do, in fact, have vital roles in enhancing, suppressing, or modifying the expression of distantly located genes. (See *S&TR*, June 2005, pp. 4–11; May 2001, pp. 12–20.) "An estimated 95 percent of the human genome is noncoding," says Gabriela Loots, a biomedical researcher in Livermore's Physical and Life Sciences Directorate. "Some of these areas act as switches to turn genes on and off. If a switch is broken, it can have just as big an effect as if the protein was mutated."

Genes must be properly expressed—the right amount in the right place—for biological processes to execute accurately. Even a single nucleotide difference in a regulatory sequence can significantly affect where, when, or how much messenger RNA a gene expresses.

Loots and postdoctoral researcher Nicole Collette led one of the first successful efforts to pinpoint a skeletal disease–associated mutation that alters a long-range regulatory element and replicates a human disease in mice. The study focused on the transcriptional regulation of sclerostin, or Sost, a growth factor that is crucial in regulating bone formation and represents a drug target for the treatment of osteoporosis. Ultimately, researchers want to develop effective nonsurgical treatments for weak or broken bones by manipulating Sost expression.

Mutations Help Pinpoint Function

Bone is a dynamic tissue. It is constantly being refashioned by osteoblasts, cells that make bone, and osteoclasts, cells that break down bone. Osteocytes comprise the bulk of mature bone and are responsible, among other roles, for making Sost. The Sost protein regulates bone turnover through a signaling pathway by which a network of so-called Wnt proteins pass signals from surface-level receptors on a cell to gene expression in the nucleus. This network is involved in many tightly regulated biological processes, including skeletal development and bone metabolism.

Research on human diseases that are triggered by mutations affecting Sost expression have helped scientists understand how Sost and Wnt signaling control bone turnover. For example, sclerosteosis, a disease in which a person's bones grow to be as much as four times thicker than average, is caused by Sost mutations. These mutations render the Sost protein nonfunctional throughout the organism, which elevates Wnt signaling in osteoblasts and subsequently increases bone formation. Van Buchem's disease is similar to sclerosteosis, albeit with somewhat less severe symptoms. This rare recessive illness intrigued biologists because of its clear association with Sost expression, despite the lack of mutations in the Sost protein-coding regions.

To more closely examine this mutation, Loots genetically engineered a human transgene to mimic the Van Buchem gene variant. Results from this study, which was funded by the National Institutes of Health (NIH), showed that a 52,000-base-pair segment of a noncoding region located a significant distance from the Sost gene is required to activate human Sost in the skeleton of a mouse. To determine which sequence within the deleted region regulates Sost, Loots compared the human Van Buchem region to the mouse genome and found several highly conserved noncoding sequences. Scientists assume that these segments, called evolutionarily conserved regions (ECRs), have an important biological role; otherwise, the segments would have been discarded as organisms evolved. (See *S&TR*, April 2005, pp. 20–22.)

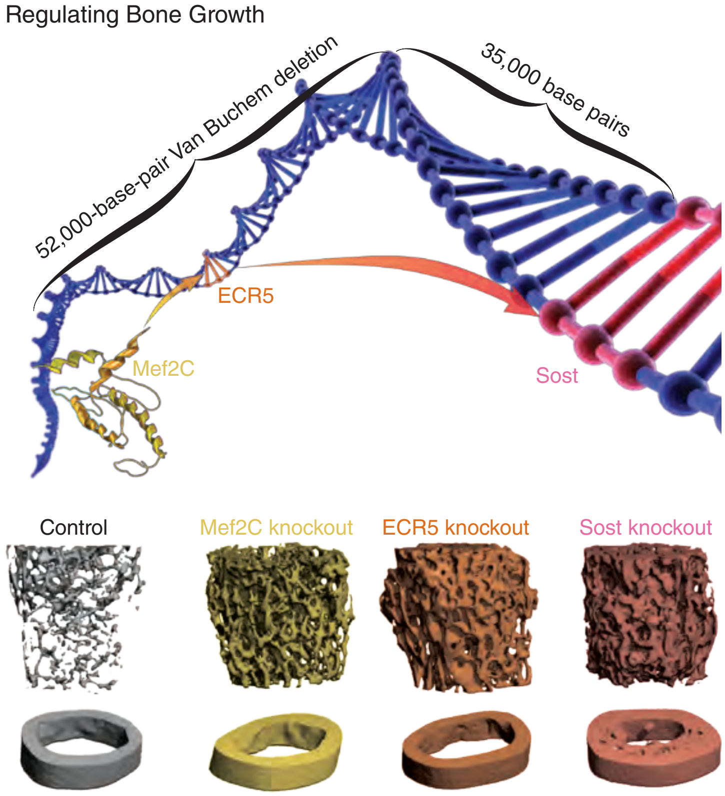
In collaboration with researchers at Novartis, Loots introduced these ECRs into osteoblast-like cells and found a 250-base-pair element, ECR5, that behaves as a transcriptional activator and most likely enhances Sost expression. Although ECR5 exhibited enhancer activity, in vitro results did not conclusively show whether the element was essential for Sost expression or whether removing it from the genome would cause Van Buchem's disease.

Narrowing Down the Possibilities

In multicellular organisms, the transcription of protein-coding genes is regulated by two groups of factors: a promoter and regulatory elements such as enhancers, silencers, or insulators. A type of DNA-binding protein called a transcription factor interacts with regulatory elements to activate gene expression. In previous work that examined patterns of transcription factor binding sites, the Livermore–Novartis collaborators predicted that a family of muscle-specific transcriptional regulatory proteins known as Mef2 (a family of four different genes, labeled Mef2A–D) might be binding to ECR5 and controlling its function. Because Sost and Mef2C were co-expressed in bone cells, the researchers examined whether Mef2C protein can further increase ECR5 activity. They found that Mef2C served as an activator, binding to ECR5 and modulating its activity.

In vitro studies in controlled environments are useful for learning how a protein carries out its function. However, complementary in vivo experiments were needed to confirm the

Biomedical researchers Nicole Collette (left) and Gabriela Loots work with genetically engineered mice at Livermore's animal care facility. Their collaborations with other organizations are helping scientists better understand how gene regulation might be used as a treatment for people suffering from bone-loss disorders.



Research involving genetically modified mice indicates that deactivating (or knocking out) the bone-growth-regulating protein sclerostin (Sost), its enhancer ECR5, or its activator Mef2C will increase bone mass, compared with that found in control mice. Mice missing the Sost gene for regulating bone turnover have the highest bone mass of all. Microscale computed tomography images of mouse femurs (bottom rows) show the dramatic difference in bone mass in adult mice. (DNA rendering by Kwei-Yu Chu.)

regulatory functions of ECR5 and Mef2C in Sost expression. With new funding from NIH, Loots and Collette teamed up with Aris Economides, a scientist at Regeneron, and Richard Harland of the University of California at Berkeley to study the interrelated roles of Sost, ECR5, and Mef2C in bone.

This study used a combination of ECR5 transgenic mice and so-called knockout mice—those with a gene sequence deactivated. The different strains carried a deletion of either the Sost gene, ECR5, or Mef2C. The mice then mated with each other, generating several knockout–knockout and knockout–transgenic strains. When Collette compared Sost expression and bone phenotypes of the different combinations, she found that mice lacking Sost, its enhancer, or its activator had denser bones than the control mice.

Microscale computed tomography analysis performed by investigators at the University of California at Davis and Regeneron revealed that ECR5 knockout mice had less bone overgrowth than those without Sost, consistent with Van Buchem and sclerosteosis bone parameters. This finding confirmed the researchers' hypothesis that the ECR5 deletion reduces the expression of Sost and is sufficient to cause the high-bone-mass phenotype observed in those with Van Buchem's disease.

For the bone parameters measured by the team, osteoblasts without Mef2C were similar to ECR5 knockout mice and humans with Van Buchem's disease—results that confirmed Mef2C's critical role in ECR5 enhancement and subsequently in Sost expression. In addition, ECR5, Sost, and Mef2C knockout mice all showed significantly elevated levels of Wnt signaling, additional evidence that the three mouse strains were generating high bone mass through the shared mechanism of reduced Sost expression in bone.

Collette notes that just because a segment has a function does not mean the function is essential. "The genome has a lot of redundancy," she says. "With Mef2C, we wanted to determine whether removing this transcription-activating protein would have a consequence. We got lucky, and it produced the same results as two high-bone-mass diseases." According to Loots, this study is the first in vivo demonstration of Mef2C's involvement in Sost regulation. Previous research had focused on characterizing its role in muscle and cartilage development.

Building Better Bones

The team's Sost findings deepen scientific understanding of long-range gene regulation and the life-long cycle of bone remodeling in humans. In addition, this work may help researchers exploit the gene and signaling pathway to treat individuals suffering from bone-loss disorders such as osteoporosis.

By 2020, half of all Americans over age 50 are expected to have low bone density or osteoporosis. Current treatments for osteoporosis simply curtail bone loss. A targeted therapy that suppresses Sost expression could boost bone formation and build stronger bones. With funding from the Laboratory Directed Research and Development (LDRD) Program, Loots is investigating how the interplay between metabolic response and genetic variation might affect targeted treatments to improve bone density.

Collette has also initiated an LDRD project, which will investigate effective Sost-related treatments for traumatic bone injury in patients such as soldiers with severe breaks that might not otherwise heal well. She notes that a quarter of all injuries sustained by U.S. troops are breaks and other bone injuries that require hospitalization, and more than 10 percent of these fracture cases result in permanent disability. Delivering Sost-suppressing antibodies to osteoblasts at the injury site could increase bone formation and reduce recovery time.

Loots and Collette are excited to see their Sost research progressing toward practical solutions for improving human health. Collette observes, "If we understand how something is built, we can figure out how to fix it."

—Rose Hansen

Key Words: evolutionarily conserved region (ECR), gene regulation, genome, knockout mice, microscale computed tomography, osteoblast, osteoclast, osteocyte, osteoporosis, sclerosteosis, sclerostin (Sost), Van Buchem's disease, Wnt signaling.

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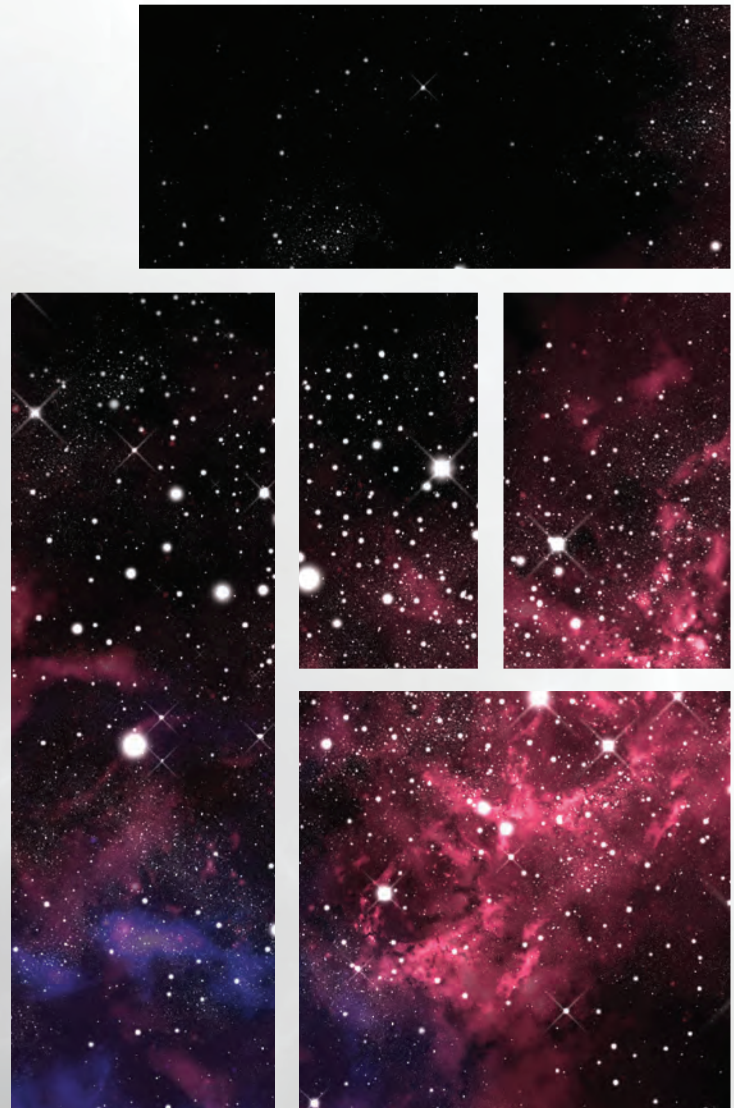
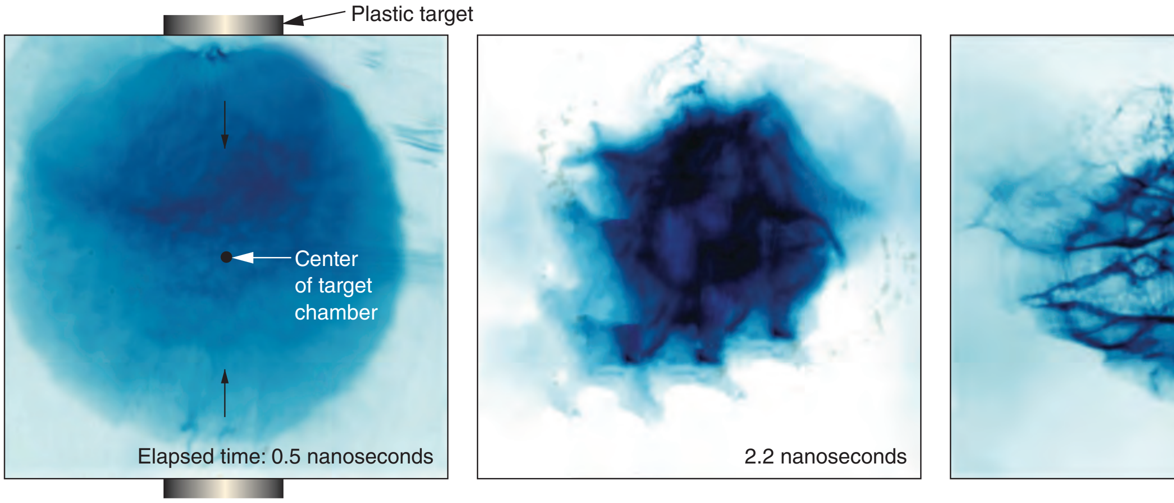
Chaotic Plasmas Give Birth to Orderly Electromagnetic Fields



ONE of the enduring mysteries of astrophysics is how highly organized structures such as vast magnetic fields stretching out for millions of light years can emerge from the frenetic motion of superhot ions and electrons that constitute a plasma. A team of Lawrence Livermore researchers has discovered that streaming plasmas created by powerful lasers appear to give rise to "self-organized" electromagnetic fields similar to those found throughout the universe, such as those that emanate from young stars or supernovae.

Using the OMEGA Extended Performance (EP) laser at the University of Rochester's Laboratory for Laser Energetics, the team discovered that supersonic counter-streaming (directed at each other) plasmas generate large, stable "structures" of electric or magnetic fields by a mechanism yet to be explained. As revealed in proton radiography images, these structures are oriented perpendicular to the direction of the two plasma flows, have detailed features, and are much larger and persist much longer than would be predicted from the chaotic motions of the plasma ions and electrons.

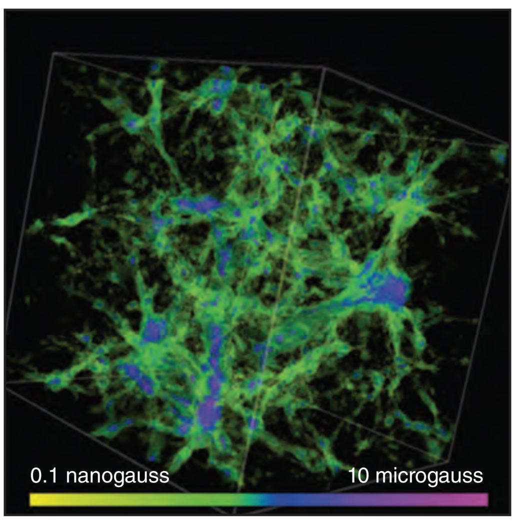


"What we observed was completely unexpected," says Hye-Sook Park, physicist and leader of the Livermore team, which includes physicist Dmitri Ryutov and postdoctoral researchers Chris Plechaty, Steven Ross, and Nathan Kugland (formerly of Livermore). "The plasmas we created moved so quickly that we expected them to freely stream past each other without causing the formation of any regular or long-lasting electric or magnetic fields."

The experiments were conducted as part of an international collaboration including Lawrence Livermore, Rochester, University of Nevada at Reno, Rice University, University of Michigan, Princeton University, University of Oxford and University of York in England, Osaka University in Japan, Laboratoire d'Utilisation des Lasers Intenses in France, and Eidgenössische Technische Hochschule in Zürich. Livermore's Laboratory Directed Research and Development Program and the International Collaboration for High Energy Density Science provided additional support.

Scientists use the term "self-organization" to describe the process of large-scale structures arising from chaotic, random activity, including the motion of plasma ions and electrons.

Throughout the universe, self-organization is evident, as in this simulated magnetic field in a cluster of galaxies.



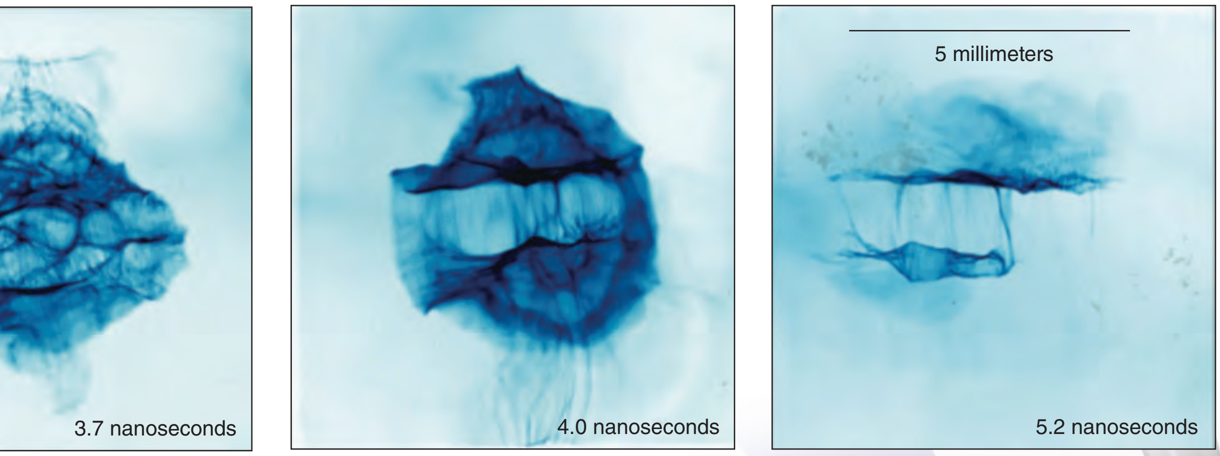
Magnetic flux density

Self-organization is believed to play an important role in a wide range of astronomical phenomena. For example, it may contribute to the creation of the organized magnetic fields that are critical to star formation and galaxy evolution. Self-organization is visible on Earth in countless ways, from sand dunes and snowflakes to a leopard's spots. As the Livermore researchers found in their experiments, self-organization also seems to occur when two supersonic plasma streams meet. The brief interactions between charged particles cause energy to be transported from smaller to larger scales.

Collisionless Shocks

In the Earth's atmosphere, shocks form when particles collide. In the near-vacuum state of outer space, particle collisions are extremely rare. However, shock waves can occur in outer space when plasma constituents pass by each other at high velocities, largely without colliding. These "collisionless" shocks can give rise to magnetic fields stretching for hundreds of light years. Collisionless shocks appear in a wide array of exotic astronomical settings such as violent solar flares, outbursts from galaxies, and supernova remnants. Closer to Earth, a collisionless shock exists where the solar wind—the stream of charged particles from the Sun—encounters Earth's magnetic field.

The Livermore team has been conducting experiments since December 2010, first at the University of Osaka's Institute for Laser Engineering and later at the OMEGA EP laser, an addition to the OMEGA laser facility that provides ultrahigh intensities for x-ray and proton radiography. The experiments focus on investigating whether intersecting plasmas created by lasers can form collisionless shocks and whether these shocks could produce large-scale electromagnetic fields. "When a star explodes, different layers of plasmas move out very fast, and

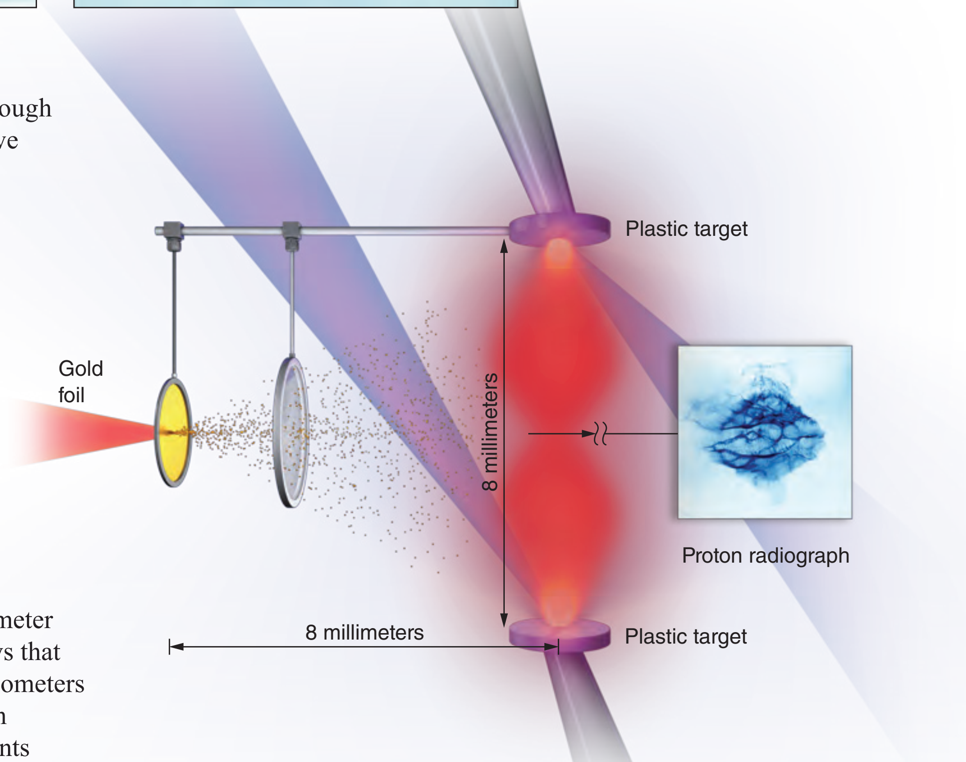


A time sequence of proton radiographs shows the evolution of self-organized electromagnetic fields, as viewed looking down at plasmas flowing toward each other. After a few nanoseconds, the early-time "chaotic" field structures become stable parallel disks, or "pancake" structures. Although this type of self-organization is observed in many astrophysics projects, it is the first one found in a laser experiment.

because of their extremely low density, they pass right through each other," says Kugland. "No shocks should form, but we do see them. Our experiments are intended to answer why they form."

Kugland notes that laser-generated plasmas initially have much weaker magnetic fields than most astronomical phenomena. In this respect, they are similar to supernova remnants, which exhibit small but well-formed fields that may be either electric or magnetic in nature. "Most astrophysical collisionless shocks can't be directly measured," he says. "We look to laboratory experiments to better understand these objects."

At OMEGA EP, the team uses two 2,200-joule laser beams that generate an intensity of about 3 quadrillion watts (or petawatts) per square centimeter. Each laser pulse, which lasts a mere 3 nanoseconds (or billionths of a second), irradiates a plastic target only 2 millimeters in diameter by 0.5 millimeters thick. The pulses create two plasma flows that shoot toward each other with velocities exceeding 1,000 kilometers per second, the same speed at which many plasmas travel in space. At these velocities, the laser-driven plasma constituents pass through largely without hitting each other, despite their relatively high densities (about 1 quintillion, or 10^{18}, particles per cubic centimeter).



At the University of Rochester's OMEGA Extended Performance Facility, the Livermore team used two 2,200-joule laser beams for collisionless shock experiments. Each beam (purple) irradiates one of two plastic targets that are 8 millimeters apart. The pulses create two plasma flows (red glows) that shoot toward each other with velocities exceeding 1,000 kilometers per second. The field generated when the plasmas interact was imaged with protons produced by focusing two 250-joule laser beams onto two gold foils (yellow). As the energetic (8.8-megaelectronvolt) protons fly though the zone where the plasma streams intersect, they are deflected by electric or magnetic fields onto a detector, which records radiographs such as in the inset and at the top of pp. 22–23. This rendering (by Kwei-Yu Chu) depicts only one proton stream.

Protons Permit Visualization

The researchers use proton radiography, the only widely available diagnostic that can capture detailed images of electric and magnetic fields in high-energy-density plasmas. The technique provides images with outstanding spatial resolution (from a few to 10 micrometers in scale) and very good temporal resolution (scaling from 1 to 10 picoseconds, or trillionths of a second).

To generate the proton beams, the scientists focus two 250-joule, 10-picosecond-long laser beams onto two 2-millimeter-diameter by 50-micrometer-thick gold foils. Either electric or magnetic fields deflect the energetic (8.8-megaelectronvolt) protons created from the gold foils onto a detector as they fly though the zone where the two plasma streams intersect. At first, the proton images (shown on pp. 22–23) reveal small-scale (about 10-micrometer-wide) striations oriented in the direction of the plasma flow. A few nanoseconds later, the images begin to show the formation of two joined parallel, "messy" structures perpendicular to the flow, possibly in response to a collisionless shock. The messiness quickly becomes more ordered, and two joined disks, or "pancakes," appear, each one about 5 millimeters in diameter. They are much larger than the scale at which kinetic plasma instabilities occur and last for about 4 nanoseconds, much longer than the duration of intersecting plasma ions and electrons.

Says Kugland, "We believe we are seeing order rise from disorder, where microscopic processes lead to macroscopic structure. Macroscopic structures emerge from turbulence throughout the universe, and it appears that self-organization can arise from microscopic plasma instabilities on a vastly smaller scale." The sharp features strongly suggest that organized fields cause the structures to form; small-scale areas of turbulence would only produce small, fleeting areas of blurring on the radiographs.

Ryutov says it is unclear what is producing the images, although they certainly depict either an electric or magnetic field or a combination of the two. "The structures we see on the proton radiographs are robust," he says. "They are definitely not an artifact of the proton radiographs, but their cause remains a mystery. The structures were a surprise to everyone, and they appear with wonderful regularity." In several shots, they have the same shape and appear at the same time. To fully understand their origin, however, the researchers need better measurements of velocity, density, and temperature.

NIF Experiments Under Planning

The team plans to duplicate the OMEGA EP experiments in late 2013 at the National Ignition Facility (NIF) at Livermore to overcome the limitations of the previous plasmas. Earlier experiments at the University of Osaka produced plasmas with relatively low temperature and moderate velocity, resulting in a high number of collisions inside each plasma flow and moderate collisions between the two. The recent OMEGA EP collisionless shock experiment also produced relatively low temperatures and relatively high intrajet (within each stream) collisions, although the plasmas were more energetic.

Park says that NIF is the only facility that can create plasmas with sufficiently high density (greater than 10^{20} particles per cubic centimeter), high flow velocity (greater than 2,000 kilometers per second), and high temperature (greater than 1 kiloelectronvolt). Under these experimental conditions, intrajet collisions will be truly negligible so that the plasma streams will more closely approximate astrophysical conditions. As a result, the NIF plasmas will be more conducive to self-organization, an environment that was probably barely reached in the OMEGA EP experiments. Ryutov says, "With NIF, we will finally reach scales that determine the underlying physics, allowing us to fully understand the phenomenon."

"NIF will generate true high-energy-density plasmas," says Kugland. "We will likely have surprises with the NIF experiments, because we will have different regimes of matter. Another challenge is how to make measurements that are meaningful in this new environment."

The team's discovery underscores the usefulness of powerful lasers in studying the physics of plasma interactions, especially the emergence of self-organization and collisionless shocks, under controlled laboratory conditions. "Laboratory experiments using lasers are enhancing scientific understanding of the generation and evolution of electromagnetic fields in space," says Park. "We believe they will also help scientists address several important questions in astrophysics."

—Arnie Heller

Key Words: astrophysics, collisionless shock, National Ignition Facility (NIF), OMEGA Extended Performance (EP) laser, plasma, proton radiography, self-organization.

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Patents and Awards

In this section, we list recent patents issued to and awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Organized Energetic Composites Based on Micro and Nanostructures and Methods Thereof
Alexander E. Gash, Thomas Young-Jin Han, Donald J. Sirbuly
U.S. Patent 8,257,520 B2
September 4, 2012
An ordered energetic composite structure, according to one embodiment, includes an ordered array of metal fuel portions and an oxidizer in gaps between the metal fuel portions. An ordered energetic composite structure, according to another embodiment, includes at least one metal fuel portion having an ordered array of nanopores with an oxidizer in them. A method for forming an ordered energetic composite structure, according to one embodiment, includes forming an ordered array of metal fuel portions and depositing an oxidizer in gaps between the portions. A method for forming an ordered energetic composite structure, according to another embodiment, includes forming an ordered array of nanopores in at least one metal fuel portion and depositing an oxidizer in the nanopores.

Energy Resolution in Semiconductor Gamma Radiation Detectors Using Heterojunctions and Methods of Use and Preparation Thereof
Rebecca J. Nikolic, Adam M. Conway, Art J. Nelson, Stephen A. Payne
U.S. Patent 8,258,482 B2
September 4, 2012
In one embodiment, a system comprises a semiconductor gamma-detector material and a hole-blocking layer adjacent to it. In another embodiment, a system comprises a semiconductor gamma-detector material and an electron-blocking layer adjacent to the material. The electron-blocking layer is made of undoped mercury–cadmium–tellurium.

Electrostatic Generator–Motor Configuration
Richard Freeman Post
U.S. Patent 8,264,121 B2
September 11, 2012
This electrostatic generator–motor design includes a stator connected to a first central support centered about a central axis. The stator elements are attached to the first central support. Similarly, a second stator is connected to a central support centered about the central axis, and the second stator has stator elements attached to the second central support. A rotor between the first and second stators includes an outer support, where the rotor is centered about the central axis. The rotor has elements in contact with the outer support, and each element has a portion that extends radially from the outer support toward the axis of rotation.

Fabrication of Transparent Ceramics Using Nanoparticles
Nerine J. Cherepy, Thomas M. Tillotson, Joshua D. Kuntz, Stephen A. Payne
U.S. Patent 8,268,230 B2
September 18, 2012
This method for fabricating a transparent ceramic uses nanoparticles synthesized via organic-acid complex combustion. Metal salts are dissolved to produce an aqueous salt solution, and an organic chelating agent is added to produce a complexed metal sol. The sol is heated to form a gel that is dried into a powder. The powder is combusted to produce nanoparticles that are calcined to make oxide nanoparticles. A green body made from the oxide nanoparticles is sintered to produce the transparent ceramic.

Cermets from Molten Metal Infiltration Processing
Richard Lee Landingham
U.S. Patent 8,268,234 B2
September 18, 2012
These cermets have lower densities and/or higher hardness than boron carbide cermet. Incorporating ceramics into boron carbide powders or using them as a substitute for boron carbide results in cermets with lower densities and/or higher hardness. The ceramic powders have much finer particle size than those previously used, which significantly reduces the grain size of the cermet's microstructure and improves its properties.

Method and System for Processing Optical Elements Using Magnetorheological Finishing
Joseph Arthur Menapace, Kathleen Irene Schaffers, Andrew James Bayramian, William A. Molander
U.S. Patent 8,271,120 B2
September 18, 2012
This method of finishing an optical element includes placing the optical element in a mount that has a plurality of fiducial marks overlapping with the element. A first metrology map is obtained for the optical element and the fiducial marks. A second metrology map is also obtained for the optical element without the fiducial marks, thus forming a difference map between the first and second maps. Mathematical fiducial marks are placed on the second metrology map using the difference map to form a third metrology map. Finally, the optical element is mounted and positioned in the fixture, the fiducial marks are removed, and the optical element is finished.

Carbon Fuel Particles Used in Direct Carbon Conversion Fuel Cells
John F. Cooper, Nerine Cherepy
U.S. Patent 8,283,078 B2
October 9, 2012
In this system, carbon particles are finely divided and introduced into a fuel cell along with a gas that contains oxygen. The finely divided particles are exposed to either carbonate salts; molten sodium hydroxide, potassium hydroxide, lithium hydroxide, or mixtures of the three; mixed hydroxides; or alkali and alkaline earth nitrates.

Large Optics Inspection, Tilting, and Washing Stand
Marion Jay Ayers, Shannon Lee Ayers
U.S. Patent 8,284,503 B2
October 9, 2012
A large optics stand provides a risk-free means of tilting large optics with ease. The optics are supported in the horizontal position by pads. In the vertical plane, saddles evenly distribute the optics' weight over a large area.

Laser Bandwidth Interlock Capable of Single Pulse Detection and Rejection
James P. Armstrong, Steven James Telford, Rodney Kay Lanning, Andrew James Bayramian
U.S. Patent 8,284,809 B2
October 9, 2012
A pulse of laser light is switched out of a pulse train and spatially dispersed into its constituent wavelengths. The pulse is collimated to a suitable size and then diffracted by high-groove-density multilayer dielectric gratings. Diffraction imparts a different angle to each wavelength. As a result, when the wavelengths are brought to the far field

with a lens, their colors have spread out in a linear arrangement. The distance between wavelengths (resolution) can be tailored for the specific laser and application by altering the number of times the beam strikes the diffraction gratings, the groove density of the gratings, and the focal length of the lens. End portions of the linear arrangement are each directed to a respective detector, which converts the signal to a 1 if the level meets a set point or a 0 if the level does not. If both detectors produce a 1, the pulse train is allowed to propagate into an optical system.

Simultaneous Acquisition of Differing Image Types

Stavros G. Demos
U.S. Patent 8,285,015 B2
October 9, 2012
This system has a device with different image components for forming an image from an area of interest and a device for illuminating that area with light containing multiple components. At least one light source is coupled to the illumination device to provide light to the illumination device containing different components that have distinct spectral characteristics and relative intensity. An image analyzer coupled to the image-forming device decomposes the image formed into multiple component parts based on the type of imaging. Multiple image-capture devices receive these different parts of the image. The image produced by the image-forming device is decomposed into multiple component parts based on type of imaging. These parts are then used to output image information. Additional systems and methods are presented.

Bio-Threat Microparticle Simulants

George Roy Farquar, Roald N. Leif
U.S. Patent 8,293,535 B2
October 23, 2012
A biothreat simulant includes a carrier with DNA encapsulated in it. A method for making such a simulant involves providing a carrier and encapsulating DNA in the carrier.

Automated High-Throughput Flow-Through Real-Time Diagnostic System

John Frederick Regan
U.S. Patent 8,298,763 B2
October 30, 2012
This automated real-time flow-through system can process multiple samples in an asynchronous, simultaneous, and parallel fashion for nucleic acid extraction and purification, followed by assay assembly, genetic amplification, multiplex detection, analysis, and decontamination. The system can hold and access an unlimited number of fluorescent reagents that may be used to screen samples for the presence of specific sequences. The apparatus works by associating extracted and purified sample with a series of reagent plugs that have been formed in a flow channel and delivered to a flow-through real-time amplification detector. The detector has multiple optical windows, to which the sample–reagent plugs are placed in an operative position. The diagnostic apparatus includes sample multiposition valves, a master sample multiposition valve, a master reagent multiposition valve, reagent multiposition valves, and an optical amplification and detection system.

Forming Foam Structures with Carbon Foam Substrates

Richard L. Landingham, Joe H. Satcher, Jr., Paul R. Coronado, Theodore F. Baumann
U.S. Patent 8,303,883 B2
November 6, 2012
With this invention, foams of desired cell sizes can be formed from metal or ceramic materials coating the surfaces of carbon foams that are subsequently removed. For example, metal is placed over a solgel foam monolith and melted to produce a metal–solgel composition. The solgel foam monolith is removed, leaving a metal foam.

High Strength Air-Dried Aerogels

Paul R. Coronado, Joe H. Satcher, Jr.
U.S. Patent 8,304,465 B2
November 6, 2012
A method for preparing high-strength, air-dried organic aerogels involves the solgel polymerization of organic gel precursors, such as resorcinol with formaldehyde, in aqueous solvents with resorcinol-to-carbon ratios of greater than about 1,000 and resorcinol-to-formaldehyde ratios of less than about 1:2.1. This approach uses a procedure analogous to that for preparing resorcinol–formaldehyde aerogels to generate wet gels that can be air dried at ambient temperatures and pressures. The method significantly reduces the time and/or energy required to produce a dried aerogel compared with the time required by conventional methods using supercritical solvent extraction. Shrinkage exhibited by the air-dried gel is typically less than 5 percent.

Discriminant Forest Classification Method and System

Barry Y. Chen, William G. Hanley, Tracy D. Lemmond, Lawrence J. Hiller, David A. Knapp, Marshall J. Mugge
U.S. Patent 8,306,942 B2
November 6, 2012
A hybrid machine-learning methodology and system for classification combines classical random forest methodology with discriminant analysis (DA) techniques to provide enhanced classification capability. A DA technique that measures an object's features to predict its class membership, such as linear discriminant analysis or Andersen–Bahadur linear discriminant technique, is used to split the data at each node in its classification trees to train and grow the trees and the forest. When training is finished, a set of *n* DA-based decision trees of a discriminant forest is produced for use in predicting the classification of new samples of unknown class.

Tunable Photonic Cavities for In-Situ Spectroscopic Trace Gas Detection

Tiziana Bond, Garrett Cole, Lynford Goddard
U.S. Patent 8,309,929 B2
November 13, 2012
Compact tunable optical cavities are provided for in situ near-infrared spectroscopy. Microelectromechanical systems–tunable vertical-cavity surface-emitting laser (VCSEL) platforms represents a solid foundation for a new class of compact, sensitive, and fiber-compatible sensors for fieldable, real-time, multiplexed gas-detection systems. Detection limits for gases with near-infrared cross sections, such as dioxygen, methane, carbon oxides, and nitrogen oxides, have been predicted to span approximately from tenths to tens of parts per million. Exemplary oxygen detection design and a process for 760-nanometer continuously tunable VCSELs is provided. This technology enables in situ self-calibrating platforms with adaptive monitoring by exploiting photonic field-programmable gate arrays.

Methods for Globally Treating Silica Optics to Reduce Optical Damage

Philip Edward Miller, Tayyab Ishaq Suratwala, Jeffrey Devin Bude, Nan Sherr, William Augustus Steele, Ted Alfred Laurence, Michael Dennis Feit, Lana Louie Wong
U.S. Patent 8,313,662 B2
November 20, 2012
A method for preventing damage to optical components by high-intensity light sources includes annealing the optical component for a predetermined period. Another method is to etch the optical component in an etchant made of fluoride and bifluoride ions. The method also includes ultrasonically agitating the etching solution, followed by rinsing the optical component in a bath.

Method to Planarize Three-Dimensional Structures to Enable Conformal Electrodes

Rebecca J. Nikolic, Adam M. Conway, Robert T. Graff, Catherine Reinhardt, Lars F. Voss, Qinghui Shao
U.S. Patent 8,314,400 B2
November 20, 2012
Methods for fabricating three-dimensional PIN structures having conformal electrodes are provided, as well as the structures themselves. The structures include a first layer and an array of pillars with cavity regions between the pillars. A first end of each pillar is in contact with the first layer. A segment is formed on the second end of each pillar. The cavity regions are filled with a material that may have a functional role, such as a neutron-sensitive material. The fill material covers each segment, and a portion of it is etched back to expose part of the segment. A first electrode is deposited onto the fill material and each exposed segment, thereby forming a conductive layer with a common contact to each exposed segment. A second electrode is deposited onto the first layer.

UWB Multi-Burst Transmit Driver for Averaging Receivers

Gregory E. Dallum
U.S. Patent 8,315,290 B2
November 20, 2012
A multiburst transmitter for ultrawideband (UWB) communication systems generates a sequence of precisely spaced radio-frequency (RF) bursts from a single trigger event. The transmitter circuit has two oscillators: a gated burst-rate oscillator and a gated RF burst or RF power output oscillator. The burst-rate oscillator produces a relatively low-frequency (megahertz-range) square wave output for a selected transmit cycle and drives the RF burst oscillator, which produces bursts of much higher frequency (in the gigahertz range) during the transmit cycle. The frequency of the burst-rate oscillator sets the spacing of the RF burst packets. The first oscillator output passes through a bias driver to the second oscillator. The bias driver conditions, or level shifts, the signal from the first oscillator for input into the second and controls the length of each RF burst. A trigger pulse actuates a timing circuit, formed of a flip-flop and associated reset time-delay circuit, that controls the operation of the first oscillator—that is, how long it oscillates, which defines the transmit cycle.

In Vivo Spectral Micro-Imaging of Tissue

Stavros G. Demos, Shiro Urayama, Bevin Lin, Ramez Moussa Ghobrial Saroufeem
U.S. Patent 8,320,650 B2
November 27, 2012
In vivo endoscopic methods and apparatuses for implementing fluorescence and autofluorescence microscopy, with and without exogenous agents, can effectively (with resolution sufficient to image nuclei) visualize and categorize various abnormal tissue forms.

Spatial Filters for High Average Power Lasers

Alvin C. Erlandson
U.S. Patent 8,320,056 B2
November 27, 2012
A spatial filter has a filter element with a second one overlapping it. The first element includes a pair of cylindrical lenses separated by a specified distance. Each lens pair has a defined focal length, and a slit filter is positioned between them. The second filter element includes a second pair of cylindrical lenses separated by a second specified distance. The second pair also has a specific focal length, and a slit filter is positioned between these lenses.

Solid-to-Hybrid Transitioning Armature Railgun with Non-Conforming-to-Prejudice Bore Profile

Jerome Michael Solberg
U.S. Patent 8,322,328 B2
December 4, 2012
This improved railgun has a system for accelerating a solid-to-hybrid transitioning armature projectile using a barrel whose bore does not conform to a cross-sectional profile of the projectile. The system contacts and guides the projectile only by the rails in a low-pressure bore volume, which minimizes damage, failure, or underperformance caused by plasma armatures, insulator ablation, or restrikes.

Nano-Laminate-Based Ignitors

Troy W. Barbee, Jr., Randall L. Simpson, Alexander E. Gash, Joe H. Satcher, Jr.
U.S. Patent 8,328,967 B2
December 11, 2012
Solgel chemistry is used to prepare igniters comprising energetic multilayer structures coated with energetic materials. These igniters can be tailored to be stable to environmental aging, that is, where they are exposed to extremes of both hot and cold temperatures (–30 to 150°C) and both low and high relative humidity (from 0 to 100 percent).

Awards

Mark Rowland, a physicist in Livermore's Global Security Principal Directorate, was named a **senior member** of the **Institute of Electrical and Electronics Engineers** (**IEEE**). Since joining the Laboratory in 1984, Rowland has primarily worked in the field of radiation detection. He has led or worked on development efforts for various instruments, including detectors that measure gamma-ray and neutron emissions, a gamma-ray camera, a large neutron scintillator multiplicity array, an x-ray fluorescent analyzer, and robots that performed fuel characterization at the Chernobyl nuclear plant in Ukraine. Since 1990, he has served as an adviser and policy expert to the International Atomic Energy Agency.

IEEE is the world's largest professional association dedicated to advancing technological innovation and excellence. Fewer than 8 percent of IEEE members attain the level of senior member, which requires 10-plus years of professional experience and significant contributions, achievements, publications, and course development or technical direction in IEEE-designated fields.

Christopher Keane and **Jane Long** were honored as **Fellows** of the **American Association for the Advancement of Science** (**AAAS**). This year, AAAS awarded the distinction to 702 members.

Keane was recognized for "distinguished technical and scientific leadership in developing inertial confinement fusion and high energy density science, and leading a robust global science community in this area." During his career at Lawrence Livermore, the Department of Energy, and the National Nuclear Security Administration, Keane has worked on increasing the collaborative efforts of U.S. inertial-confinement fusion and high-energy-density science research in the United States and internationally. He currently serves as director of the National Ignition Facility's User Office.

Long, who recently retired from the Laboratory, was recognized by AAAS for "distinguished contributions to assessing the societal implications of technology development, including in areas of climate change, geoengineering, nuclear waste and energy technology." A senior contributing scientist for the Environmental Defense Fund, Long is also a visiting researcher at the University of California at Berkeley, consultant for geoengineering at the Bipartisan Policy Center, and chairwoman of California's Energy Future Committee for the California Council on Science and Technology. During her tenure at the Laboratory, Long served as the principal associate director at large, a fellow in the Center for Global Security Research, and associate director for Energy and Environment.

Laboratory scientist **Steve Homann** received a **Secretary of Energy Achievement Award** for his work on the Mars Science Laboratory Multi-Mission Radioisotope Thermal Generator (MSL MMRTG) team. This award is bestowed on a group or team of employees who together accomplished significant achievements on behalf of the Department of Energy.

Between June and November 2011, the MSL MMRTG team delivered a radioisotope thermoelectric generator to the National Aeronautics and Space Administration (NASA) for the MSL mission, which launched on November 26, 2011. As senior science adviser, Homann played a lead role in the radiological emergency preparedness system designed to monitor a NASA launch.

Plastic scintillator technology developed by Livermore researchers won **first place** in the best nuclear/radiation detection category in the fourth annual **Homeland Security Awards** competition sponsored by ***Government Security News***. The new technology is the first plastic material that can efficiently distinguish neutrons from gamma rays. Laboratory researcher Steve Payne leads the plastic scintillator development team with materials scientist Natalia Zaitseva. The technology has been commercially licensed to Eljen Technology in Texas.

Advanced Engineering Delivers More Exact Weapons Performance

Lawrence Livermore is one of three National Nuclear Security Administration laboratories that collaborate with military research laboratories on critical projects for the Joint Department of Defense/Department of Energy Munitions Technology Development Program (JMP). Over the last decade, Livermore's design efforts have focused on munitions that improve near-field lethality and reduce collateral damage. The Laboratory's long-term investments in computational codes, computing and manufacturing infrastructure, and engineering expertise provide the necessary resources to help speed delivery of new weapons technologies to sponsors. In 2010, Livermore completed a project in partnership with the Air Force Research Laboratory, Air Armament Center, and a defense manufacturer to produce the BLU-129/B munition, which enables warfighters to more readily conduct operations in urban environments. Capitalizing on previous JMP work in advanced energetic and structural materials, the BLU-129/B project was a marked success for the Laboratory and its partners. Additional JMP-related work includes research on firing systems, computational mechanics and materials modeling, warhead applications, technologies to penetrate hard targets, and energetic materials. Scientists and engineers are also exploring how other materials could be applied to future weapons to enable more customized functionality.

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On the Path to Ignition

Livermore researchers at the National Ignition Facility (NIF) have produced states of matter never before achieved in a laboratory. NIF experiments have generated temperatures and densities that exceed those at the center of the Sun. The goal is to create a self-sustaining burn of fusion fuel—ignition. Precise implosion-optimization experiments began in May 2011 and have since produced unprecedented high-energy-density environments. In current experiments, scientists are working to increase the density of the fusion fuel's "hot spot" by a factor of three while keeping the temperature at the same level NIF has already achieved. Under these conditions, the fusion reaction rate would be sufficient to generate ignition. Experiments are guided by an improved model that explains the complex interactions between NIF's laser beams and the plasma created when the beams hit the inner walls of the hohlraum—a metal can holding the fusion-fuel capsule. Symmetry of the capsule implosion has been improved by adjusting the wavelengths of the inner and outer cones of laser beams, making beam pointing more precise, and perfecting a laser pulse of four precisely timed shocks.

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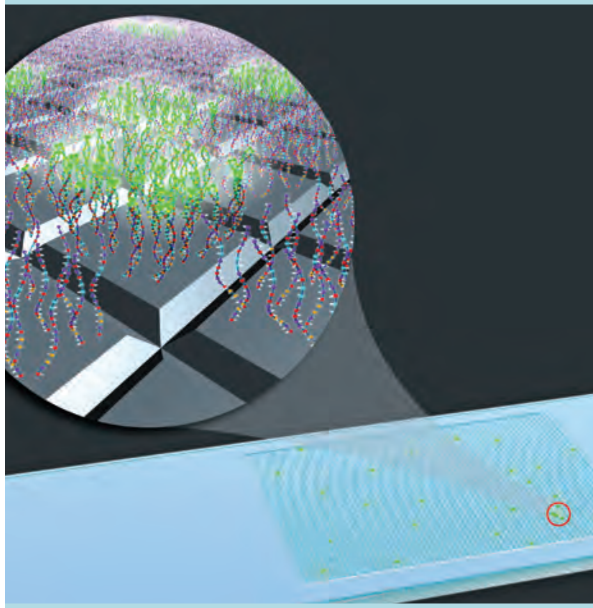
Coming Next Issue

Microarray Pathogen Detection



A new technology rapidly identifies nearly 6,000 disease-causing microbes such as viruses and bacteria.

Also in April/May

- *Scientists can now fabricate fiber lasers and amplifiers with extremely high powers and energies thanks to the installation of a fiber draw tower at the National Ignition Facility.*

- *For nearly two decades, Laboratory researchers have played a key role in the international Megatons to Megawatts Program.*

- *The two-stage gas gun at JASPER, the Joint Actinide Shock Physics Experimental Research Facility, fires its 100th shot in support of stockpile stewardship.*

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